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BIOMASS AS A SOURCE OF ENERGY FOR

Kwame Nkrumah University of Science And

Technology Ghana

School of Technology

2017

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Mechanical and Production Engineering

ABSTRACT

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Title	Biomass as a Source of Energy for Kwame Nkrumah University of Sciences and Technology Ghana.
Year	2017
Language	English
Pages	50
Name of Supervisor	Pekka Ketola, Senior Lecturer

Renewable energy has become an interesting and viable option and solution to promote sustainable development in the energy sector. The availability of biomass in a location provides the potential for institutions to use it as an alternative or first-choice energy source.

The objective of this thesis was to provide an evaluation of how biomass can be used as a source of energy for the Department of Animal Science at the Kwame Nkrumah University of Science and Technology in Ghana. In addition, this thesis assesses the environmental and social impacts of the biomass technology for providing electricity in the school. This project thesis is essential for the socio-economic development of Ghana as a whole because biomass accounts for about 64% of primary energy in the country.

The thesis evaluated the location of a plant close to the school where different types of feedstock such as cow manure, pig manure, goat manure among others, can be transported easily to the plant. Based on the findings of this research, the Department of Animal Science requires 0.013% of feedstock to produce electricity. Environmentally, biogas production is beneficial because there is no burning to produce CO_2 in the atmosphere. Similarly, a biogas plant in local communities provides income opportunities to inhabitants while making proper use of the waste generated from the farms. All in all, electricity can be produced for the Department of Animal Science with biomass. It is economically viable and also beneficial to the environment.

Keywords Biomass, renewable energy

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ABBREVIATIONS

AD	Anaerobic Matter
OM	Organic Matter
DM	Dry Matter
CH_4	Methane
CO_2	Carbon Dioxide
ECG	Electricity Company of Ghana
CHP	Combine Heat and Power
RPR	Residue to Product Ratio
TJ	Tera Joule
MW	Megawatt
KW	Kilowatt
KNUST	Kwame Nkrumah University of Science and Technology

1 INTRODUCTION

1.1 Background

Biomass is obtained from plant and other animal residues in which solar energy is converted into organic matter /1/. Biomass can be classified into the following types:

- ❖ Agricultural crops and residues;
- ❖ Dedicated energy crops (herbaceous and tree species);
- ❖ Forestry products and residues;
- ❖ Residues and by-products from food, feed, fibre, wood, and materials processing plants. /2/.

Biomass is used widely in the world and is widely used across the globe, it can be grouped into states namely biodiesel, (fuel gotten from crop), biogas (waste products or sewage and animal dung) and solid biomass (gotten from wood). It has been found that about 2.5 billion people in developing countries use biomass for cooking /3/. In Ghana about 84% and 13% of the rural household use firewood and charcoal respectively. The other two which are also available abundantly are not used to its fullest especially in one of the well-known university farm in Kumasi in the (Ashanti Region).

Therefore, the purpose of this project is to make good use of the livestock and crop residue waste by using it to generate energy (electricity) for KNUST School farm. Kwame Nkrumah University of science and Technology (KNUST) is a tertiary institution that teaches higher specific capacities of higher learning ranging from undergraduate to postgraduate degree or diploma programmes. Tertiary institutions are normally occupied by junior members (students), Faculty/Academic members (Lecturers) and Administrators.

While administrators work about 8-10 hours a day throughout the academic year, lecturers and students are available as and when lectures are in session as well as official gatherings. As a result, lecturers and students are not around throughout the Academic year since they go on vacation. Administrators are often only entitled to public holidays, annual/casual leave as well as weekends (for most institutions but not all). Tertiary institutions use energy in many different ways which include:

- Staff (Faculty members and Administrators) and Students using the internet and their technology devices for official work, assignments and research
- Science students working in the laboratory
- Students using the computer laboratory
- Faculty members and Students using projectors in lecture halls
- Servers that supply internet having constant power.

There is therefore a high potential to save energy without wholly being dependent on the national supplies. Nevertheless, since tertiary institutions are engulfed with numerous lecturers as well as other administrative assignments daily, there is a need for constant power supply, thus demand on electricity is often high. Universities are designed to meet the requirement of junior members (students), faculty members (lecturers) and administrators in order to provide a good working environment for everybody. Provision of a conducive recovery and working environment for students and staff is necessary as it will result to significant economic benefits through customer and employee satisfaction, such working environment can only be achieved with constant power supply. This contributes to high energy demand typical with the tertiary institution. Biomass as a source of energy can be used to subsidize the hydroelectric energy produced by the official energy supply company, that is, the Electricity Company of Ghana (ECG), which can be very vital especially in the situation of the power fluctuation crisis popularly known as "DUMSOR" in Ghana. The use of renewable energy can also play a key role in reducing greenhouse gas pollution. In recent years increased concern about the environment, and in particular the environmental impacts of conventional energy systems e.g. global warming, acid rain, has revitalized an interest in renewable energy. With little or no net emissions of polluting gases, renewable energy sources are seen as part of the solution to these problems.

1.2 Aim

The aim of this thesis is to see how biomass production can be used best in energy generation and also to look at the benefits when it is used for energy production, its environmental impact, and social impact in terms of electricity production. The purpose of this thesis is also to look at the amount of energy obtained of the feed stock and how best to eliminate the power fluctuation (dumsor) crisis to improve and achieve the level of production that will meet the energy demand of the KNUST farm. In generating biomass energy for the KNUST Farm, it will be mainly for an alternative power supply to that of the National grid due to power fluctuations. The power will be used for the following:

- To aid in preservation
- For lighting
- To support devices, equipment and machines
- To aid in administrative work

1.3 Research Objective

The main objective of this project is to collect energy data from KNUST farm in the Ashanti Region and to analyse the data to see how effective it can be used in bioenergy generation. The followers are the research objective needed for the research.

- To determine the current energy demand of KNUST and estimate future increase demands.
- To analyse best and most available feedstock considering their gas value for anaerobic digestion and possible backup feedstock.
- To analyse the cost of energy from that being used now.
- To analyse the cost of using biomass to generate KNUST energy demands.
- To compare the cost analysis of both ways of energy supplies.

1.4 Research Design

This aspect of the research basically consists of the methods adopted by the researcher in carrying out the research work. The methods used for the research are both qualitative and quantitative.

1.4.1 Methods of Data Collection

The following measures were adopted research work in both primary and secondary sources of information for the study.

- Internet
- Observation
- Interview
- Photographs
- Figures, pie charts and graphs

1.4.1.1 Internet

Most research works were collected from different web sites which helped to collect information in completing this project. Some pdf documents related to the topic of the research were also acquired on the internet to help to make this research a success.

1.4.1.2 Observation

Observation served as pillar of faith to judge in most cases between pretence, cover-ups and decoding of information, especially where respondents were not ready to give out certain information. Observation not only helped to collect additional data but also to appreciate the reality of the problems in question. It also helped in the analysis of the data collected. This is because the way people reacted to the topic under study and some questions which were asked made it easier to detect whether the data given was authentic or not.

1.4.1.3 Interview

Interviews were conducted at the University's Farm. Here, some staff at the University Farm was interviewed. The Head of Department for Animal Sciences was also interviewed. In addition, some lecturers and students of the Departments also had the opportunity to be interviewed.

1.4.1.4 Photographs

Photographs are visual aids which give factual evidence of data collection. The pictures taken show the reality of research and how biomass production can be used best in energy generation and also to look at the benefits when it is used for energy production, its environment impact, and social impact in term of electricity production in the KNUST Farm.

1.4.1.5 Figures, Charts and Graphs

The research contains figures, graphs, and pie charts to give a better description of the research findings. It brings out how many people were contacted to make this research a good one as well as the kind of answers given in relation to the data collected. This was further represented in percentage form since it was only a part of the animals on the KNUST Farm.

2 BIOMASS

Today, biomass in Ghana contributes to about 64% of the primary energy in the country /4/. However, modern biomass energy applications are increasing rapidly both in the industrial and developing countries /5/. Biomass energy is not a transition fuel as it has often been portrayed, but a fuel that will continue to be the prime source of energy for many people for the foreseeable future. According to IEA Energy statistics /6/:

> *"Over 2.6 billion people in developing countries will continue to rely on biomass for cooking and heating in 2030 . . . this is an increase of more than 240 million from current use. In 2030 biomass use will still represent over half of residential energy consumption . . ."*

Bio-energy having a long term future must be able to provide affordable, clean and efficient such as electricity and liquid-gaseous fuels.

2.1 Biofuel

Biofuel is increasingly being used to refer specifically to liquid and gas fuel derived from biomass./7/

Biofuel is a fuel which can be obtained from biological raw materials which nowadays can be used as substitute to petroleum fuels /8/. Biofuels are obtained by processing these biological materials to produce biodiesel, bioethanol and biogas. Biofuels can be used to produce electricity, liquid, gaseous and solid /9/. Liquid biofuels are classified as first-generation and second-generation biofuels.

2.1.1 First-generation of Biofuel

First-generation biofuels are the ones currently found in the market mostly. They are generally made from sugars, grains or seeds. Typical first generation biofuels are sugarcane ethanol, starch-based or corn ethanol, biodiesel /10/.Biodiesel is usually referred to as a mixture of fatty acid methyl esters obtained from vegetable oils and animal fats via trans-esterification reaction. Oils from the following feedstock are used for biodiesel: rapeseed, soybean, jatropha, oil palm, camelina, safflower, and coconut. /11/

Figure 1. Bus run by biodiesel

Bioethanol is ethanol that is obtained from the conversion of carbon-based feedstocks that are considered renewable. Some of the feedstocks for bioethanol are as follows: sugarcane, sugar beet, sweet sorghum, corn, cassava, wheat, and cellulose. The principle fuel used as a petrol substitute for road transport vehicles is bioethanol. Bioethanol fuel is mainly produced by the sugar fermentation process, although it can also be manufactured by the chemical process of reacting ethylene with steam. /12/

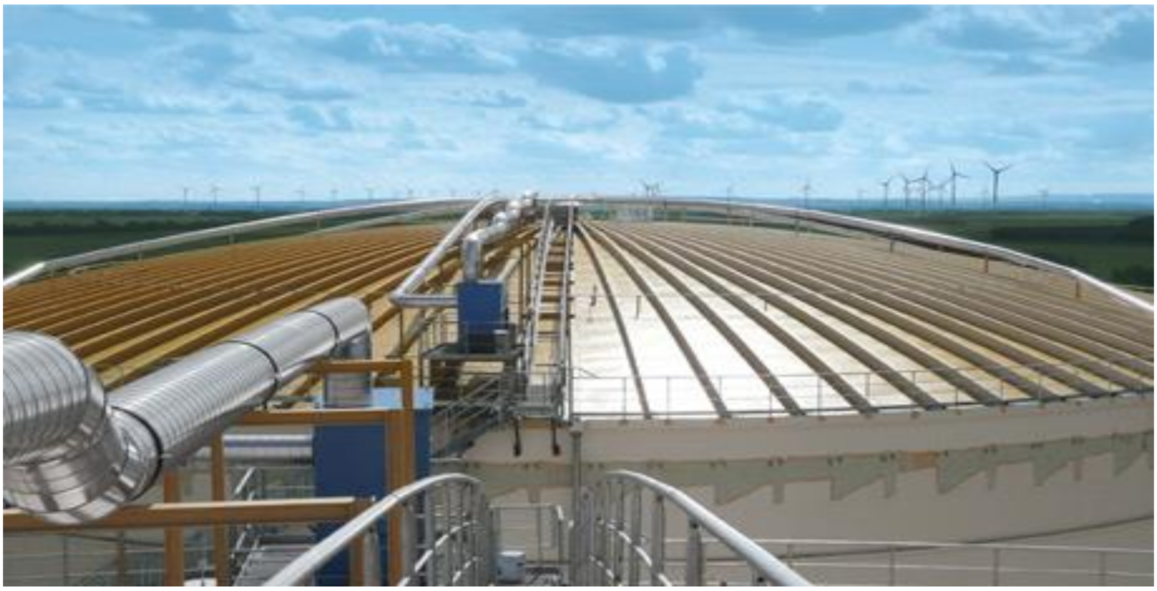

Figure 2. Plant being run by bioethanol

2.1.2 Second Generation of Biofuel

Second generation biofuels are generated from other forms of biomass. They are obtained from both plants and animal materials such as woody crops, agricultural residues or waste. One of the conversion technologies of second generation of biofuel includes biogas.

Biogas is a gas obtained from the mixture of methane (CH_4) and carbon dioxide (CO_2) by anaerobic reaction. It can be utilized for many purposes, including lighting, heating and power generation at the individual and community levels /12/. The feedstocks that may be used are: slurry or manure (e.g. from dairy farms or “industrial farming” involving large feedlots), city sewage and refuse, farming crop residues (e.g. straw or parts of cereal or fodder plants not normally harvested), residue from industry -food processing, brewing and distilling, the production of materials, such as pulp, paper and pharmaceuticals /13/.

Figure 3. Pipe carrying biogas /39/

2.2 Agricultural and Biomass Resources in Ghana

Crop production in Ghana is affected by a lot of factors including the degradation of land, improper field development, use of low-yield varieties, organised seed production and distribution systems, and inadequate storage structures /14/. Aside from the commercial plantations such as cocoa, rubber, palm oil, and coconut production, and to a lesser extent, rice, maize and pineapples, about 90% of farms in the country are less than 2 in size /15/.

In Ghana, energy crops that have potential as feedstock's for biofuel production include sugarcane, sweet sorghum, maize and cassava for ethanol, and oil palm, coconut, sunflower, soy bean and jatropha for biodiesel ./16/

Biomass resource include wood and wood waste, agricultural crops and their waste by-product, municipal solid waste, animal wastes, waste from food processing, aquatic plants and algae /17/.

2.3 Agricultural Residues

Agricultural residues include crop residues left on the farm such as rice straw and stalk, maize/corn, sorghum, and millet, and cocoa pods, cocoa husk, coconut shell and husk, rice husk, oil seed cakes, sugarcane bagasse, and oil palm empty fruit bunch (EFB) /14/. One of the most underutilised residues in Ghana is rice straw and husk. They are usually burnt after harvesting. Some of the residues are also used as a substitute for firewood.

3 BIOMASS TECHNOLOGIES

There are several ways of converting biomass resources to energy as shown in (Figure.4). This is dependent on the type of feedstock variable in mass and density, size, moisture content and also intermittent supply of its state. These processes are direct combustion or thermal conversion, thermochemical processes, biochemical processes /18/.

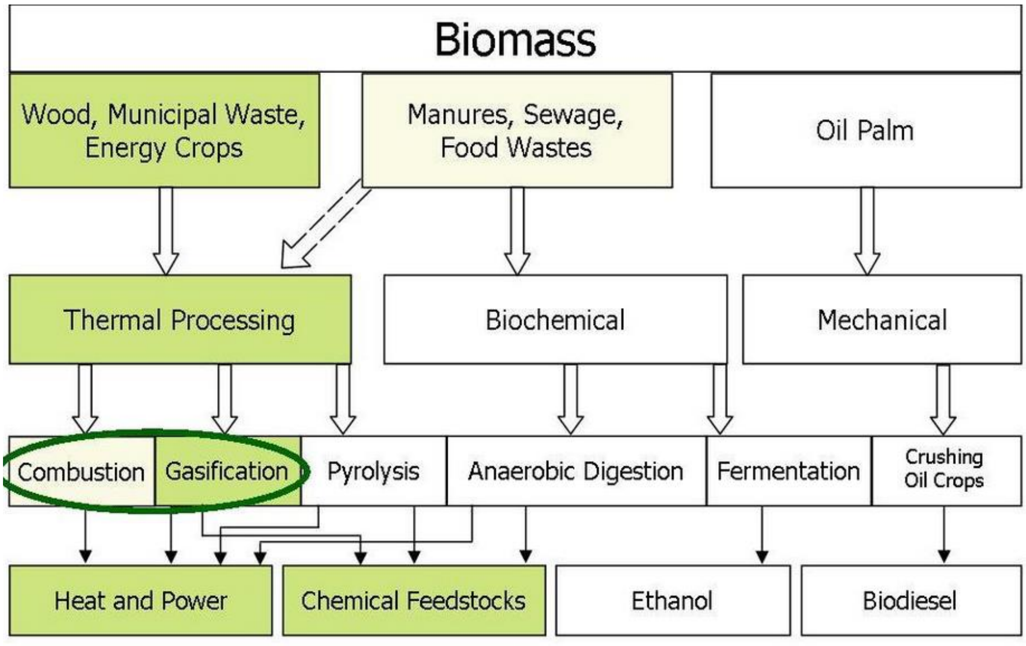

Figure 4. Different process of converting biomass into energy/18/

3.1 Direct Combustion

Biomass combustion is the oldest form of combustion existing in the world but the same time the complex system to manage. Combustion is the process where fuel in combination or contact with oxygen to produce heat. Statistics shows that only about 11% of fuel used in the world is biomass. About 90% of the world's primary energy comes from combustion produce heat /19/. Figure 5 below shows the combustion diagram and how it occurs.

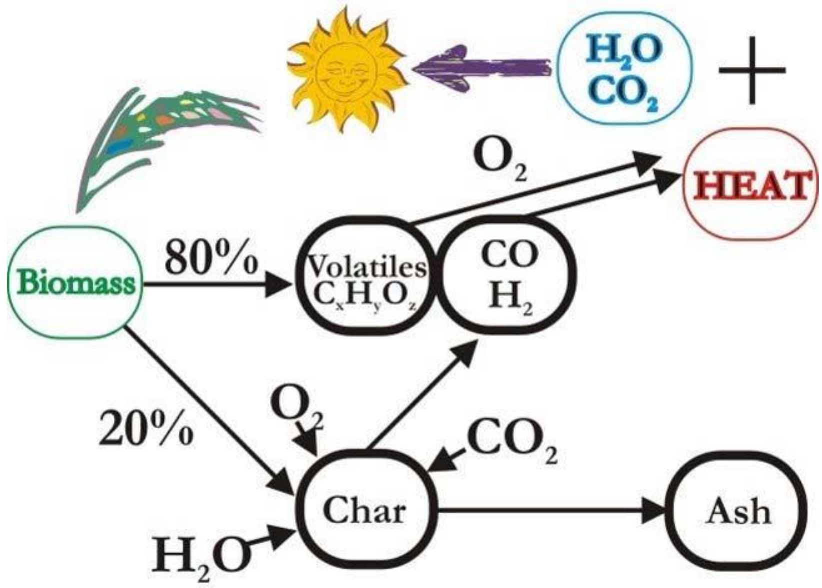

Figure 5. Biomass combustion diagram and carbon cycle closed loop./19/

3.2 Thermochemical Process

Thermochemical processing is the use of heat to promote chemical transformations of biomass into energy and chemical products. There are six processes known as combustion, slow pyrolysis, Torre faction, fast pyrolysis, flash pyrolysis, and gasification.

Combustion, gasification, and pyrolysis are methods that are referred to as thermochemical conversion technologies of biomass, which can be used to produce heat, electricity, or gaseous or liquid intermediates for upgrading to liquid fuels or chemical /19/. However, the compounds produced by thermochemical conversion of biomass and their relative amounts typically depend on process conditions i.e. temperature, pressure, feed rate, time of heating, particle size of biomass, and any quenching processes that are applied /20/.

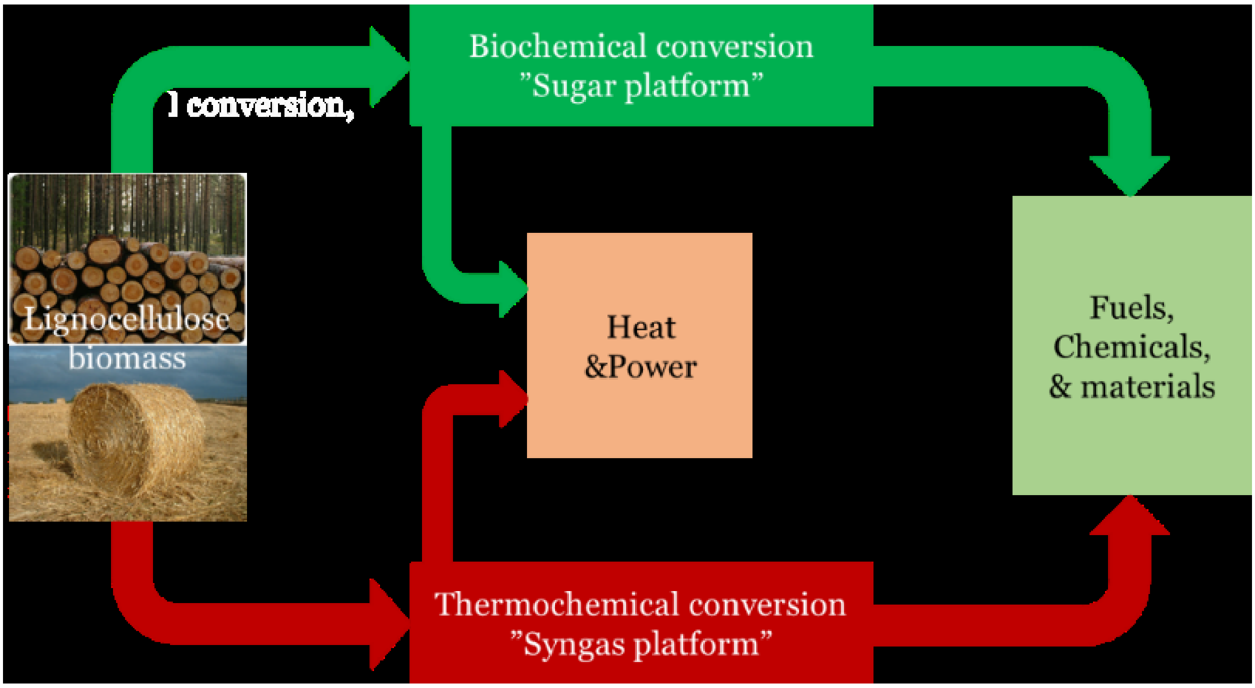

Figure 6. Overview of biomass conversion pathways./36/

3.2.1 Gasification

Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures not less than (>700 °C), without combustion, with a controlled amount of oxygen and/or air. The resulting gas mixture is called *syngas* (from *synthesis gas* or *synthetic gas*) or *producer gas* and is itself a fuel. In addition, the high-temperature process refines out corrosive ash elements such as chloride and potassium, allowing clean gas production from otherwise problematic fuels. The gasification of fossil fuels is currently widely used on industrial scales to generate electricity /21,/.

3.2.1.1 Types of Gasifiers

Gasifiers are classified according to how it interacts with oxygen and biomass in the gasifier. There are three types of gasifiers (Figure 7); downdraft, updraft and crossdraft. The choice of one type of gasifier over other is dictated by the fuel, its final available form, its size, moisture content and ash content /22/.

- **Updraught Gasifier:**

- ❖ Biomass flows downwards, and gas/air flow upwards
- ❖ Simple construction
- ❖ Tar content in gas high
- ❖ Most suited for thermal applications

● **Downdraught Gasifier:**

- ❖ Biomass moves downwards, so do air/gas
- ❖ Gas passes over high temperature zones: low tar
- ❖ Most suited for engine/gas turbine applications

● **Cross-draught Gasifier:**

- ❖ Biomass moves downwards, air/gas flow horizontally
- ❖ Suitable for high capacity systems
- ❖ Tar content is high

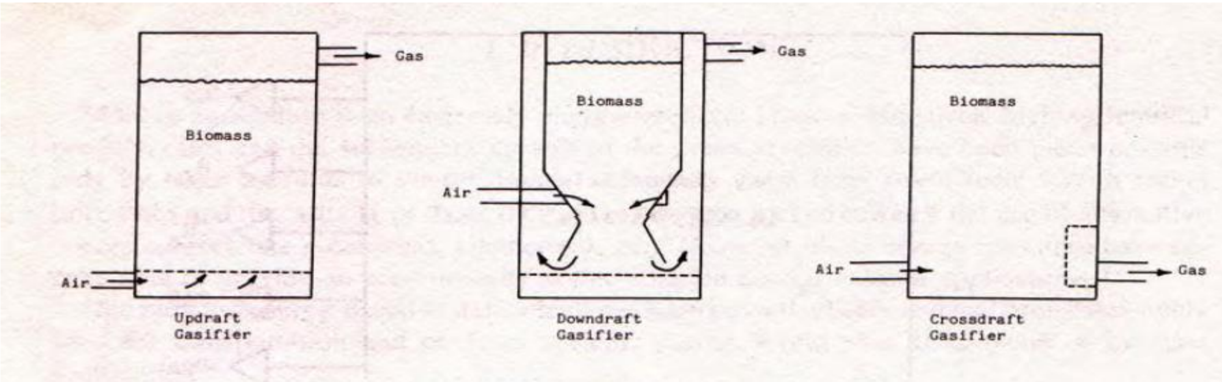

Figure 7. Various types of gasifier

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are:

a) Drying of fuel

b) Pyrolysis – a process in which tar and other volatiles are driven off

c) Combustion

d) Reduction

Figure 8 shows schematically of an updraft gasifier with different zones and their respective temperatures. Figure 6 and 7 show these regions for downdraft and crossdraft gasfiers respectively /22/.

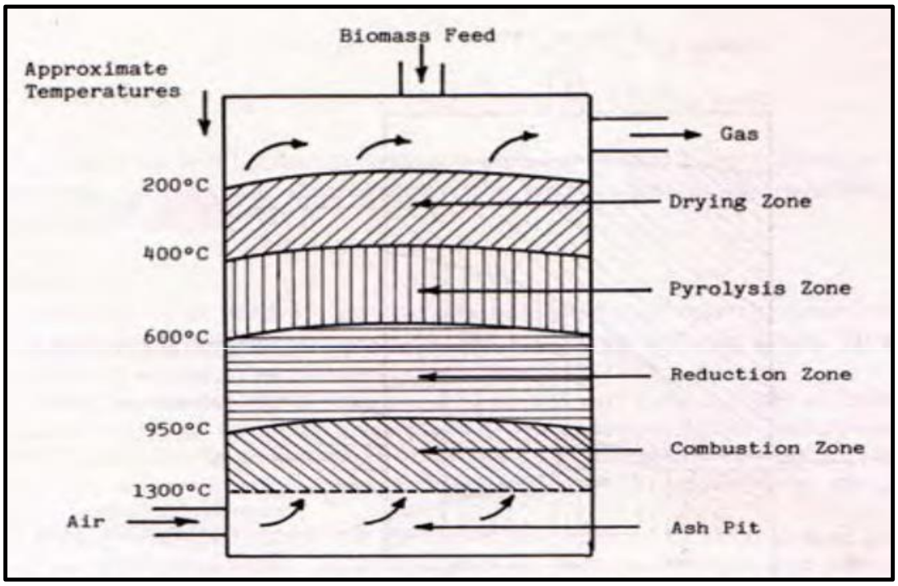

Figure 8. Various zones in updraft gasifier

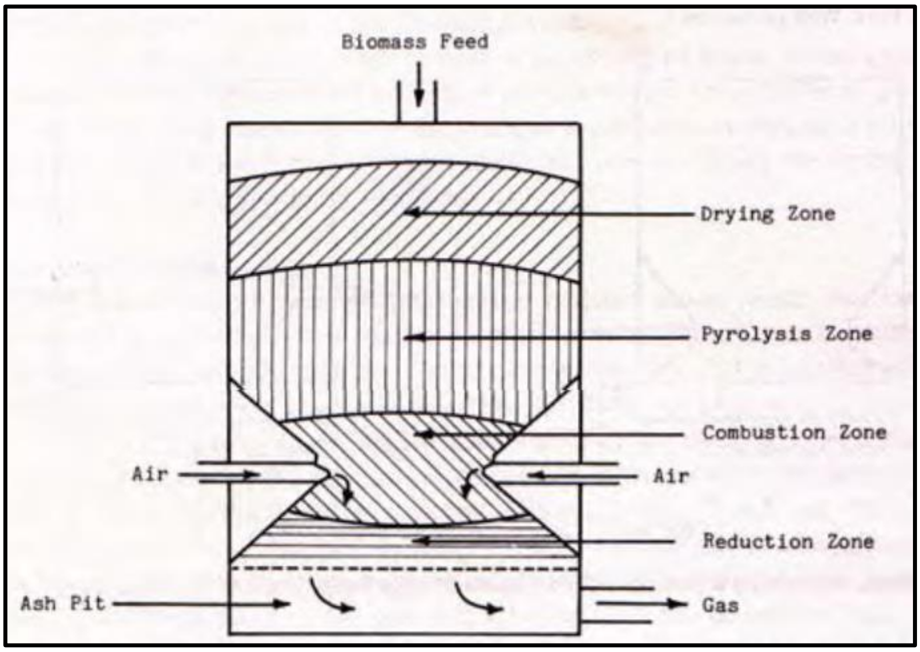

Figure 9. Gasification process in downdraft gasifier

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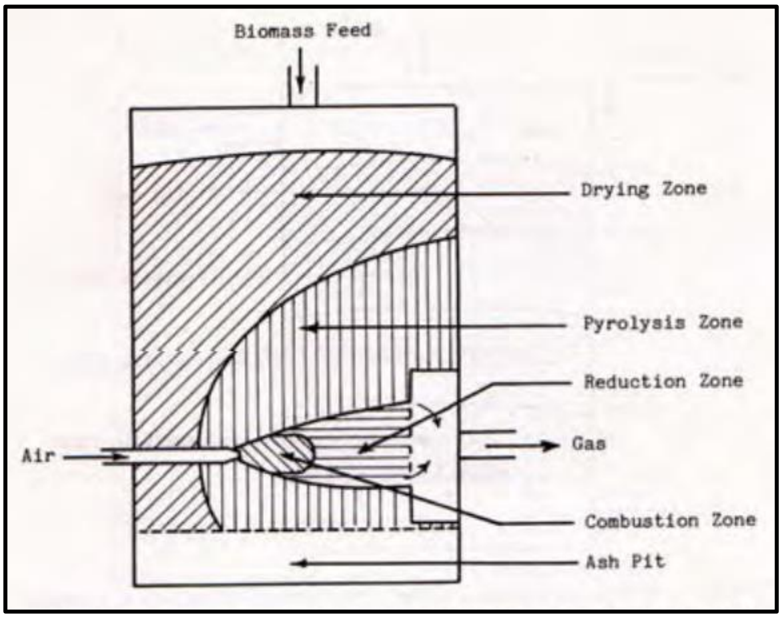

Figure 10. Gasification process in crossdraft gasififer.

3.2.2 Pyrolysis

Pyrolysis is when heat is applied to the feedstock in the absence of oxygen to break down long chain molecules to complete combustion. In this process, syngas is produced from biomass feedstock of waste, and the syngas comprises a mixture of hydrogen, volatile organic compounds and carbon monoxide. Changing the process conditions allows the production of liquids similar to diesel and other variety of products /19/.

3.2.3 Torre faction

Torre faction is similar to pyrolysis, the same as the conversion of biomass with the application of heat in the absence of oxygen to a temperature of 200 to 400°C, and also the heat is lower than that of pyrolysis. In this process, water and cellulose is removed, hemicellulose and lignin are partially decomposed in the Torre faction process. The end product is an energy dense solid fuel frequently referred to as “bio-coal” /19/.

3.3 Biochemical Process

Biochemical conversion is a pathway to the production biomass shown Figure 6. It involves the hydrolysis of cellulose and hemicellulose into simple sugars as well as their processing into other form of fuel by fermentation of organism /23/.

In the past 80 years there have been attempt to make various technology in making the process cost effective for the process to occur /24/. There are processes required to complete the conversion process namely: pre-treatment, hydrolysis of cellulose, and fermentation of lignocellulose derived sugars. Enzymatic processes are used in converting the cellulose to glucose and are regarded as the most attractive way /25/. Nevertheless, pre-treatment is vital for enzyme catalysed cellulose conversion because of structural characteristics of biomass /26/. It actually comes with an objective of removing barriers refractory of biomass by indirect factors and improving direct factors which enhance the cellulose accessibility to enzymes that would degrade carbohydrate polymers into simple sugars /27,28/. A Schematic representation of biomass in pre-treatment can be seen in figure 11 below

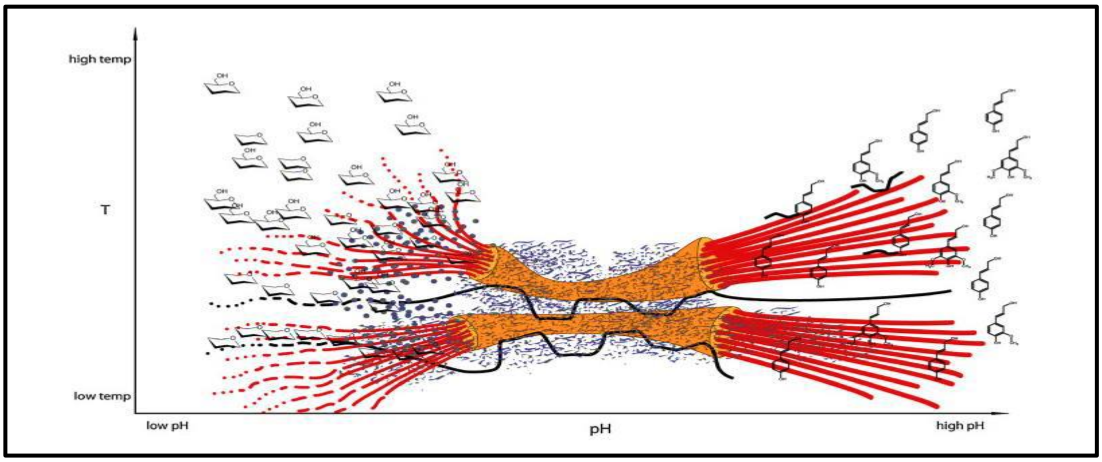

Figure 11.Schematic representation of lignocellulose biomass affected by the pre-treatment temperature and the ph. Orange and red tubes indicate cellulose fibrils and micro fibrils, respectively; black curved lines illustrate hemicellulose; gray 'veil and dots' indicates lignin (Pedersen and Meyer 2010, reprinted with permission)./37/

3.3.1 Anaerobic Digestion

Anaerobic digestion is the man-made process of harnessing the anaerobic fermentation of wastes and other biodegradable materials. Anaerobic microbes can be harnessed to treat problematic wastes, produce a fertiliser that can be used to replace high carbon emission chemical fertilisers. It also is the process that results in the production of bio-gas, which can be used to provide renewable power using biogas cogeneration systems/34/.

In anaerobic digestion, bacteria are only active in the absence of oxygen. There are three temperature ranges in which specific bacteria can live, namely psychrophilic, mesophilic and thermophilic. Thermophilic bacteria have the highest productivity, but most digesters use mesophilic bacteria due to it felicity to change and to be controlled simply. Benefits of anaerobic digestion and biogas are:

- Production of renewable power through combined heat and power cogeneration
- Disposal of problematic wastes
- Diversion of waste from landfill
- Production of a low-carbon fertiliser
- Avoidance of landfill gas escape and reduction in carbon emissions

3.4 Retention Time

The retention time is a time period which the substrates stay in the digester, these help in the biogas yield, but the optimal biogas production depends on the temperature in the digesters. There are three basic temperature ranges in which the bacteria are most active. The table below shows the thermal stage and retention time.

Table 1. Thermal Stages and Retention Time /34/

THERMAL STAGE	**PROCESS TEMPERATURES**	**MINIMUM RETENTION TIME**
Psychrophilic	< 30 C	70 to 80 days
Mesophilic	30 to 40 C	30 to 40 days
Thermophilic	40 to 55 C	15 to 20 days

The pH value in the anaerobic digester should be about 7 to 8. It should be given specific attention in cases of co-digestion of acid substrates (waste from food processing companies).

Biogas consists of primarily methane and carbon dioxide, together with some minor quantities of other gasses.

The composition of biogas from anaerobic in terms of its component and the volume of percentage in the substance is shown in Table 2.

Table 2. Composition Biogas in Percentages/34/.

COMPONENT	VOLUME PERCENTAGE
Methane (CH_4)	50–80%
Carbon dioxide(CO_2)	50–20%
Nitrogen (N_2)	<1 %
Hydrogen (N_2)	<1 %
Ammonia (NH_3)	<1 %
Hydrogen sulphide (H_2s)	<1 %

3.5 Biogas Yield and Sizing of Digester Formulas

The theoretical maximum biogas yield is obtained when the process requirements are in range. The biogas yield depends on the features of the substrates. Below are some important properties/34/.

- Dry matter (DM): percentage of dry matter in the substrate.
- Organic matter content (OM): the organic fraction (%) in the dry matter.
- Organic dry matter (ODM): the organic part of the substrate = (DM x OM)
- Maximum specific biogas production (in m3/t ODM).

The total biogas production is calculated using this formula/34/:

Biogas production = amount of substrate (t) x DM (%) x OM (% of DM) x maximum biogas production (m^3/t ODM)

For example, 2000 t of pig manure has a dry matter (DM) content of 8%, of which 80% is organic matter (OM). The maximum biogas yield is 450 m^3/t ODM.

The biogas production from the digester = 2000 t x 8% DM x 80% OM x 450m3/t ODM = 57600 m3 biogas.

Co-substrates are usually added to the substrate to increase the biogas yield especially when they are wet. Co-substrates can be obtained from different sources such as leftover silage, other agriculture waste, and crops can even be grown for the purpose of anaerobic digestion/34/.

Below is a formula which can be used to determine the theoretical biogas production of substrate and co-substrate combined.

BP = [Ma×DM×OM DM (B×OM)×100]+[Cs×DM×OM DM×(B OM)×1000].(1)

Where
BP = Biogas production (m^3yr)
Ma = Manure (t/yr)
DM = Dry matter content (m)
OM = Organic matter content (m)
B = Biogas (kg)
Cs = Co-substrate

For example, 1000 m3 of cattle manure and 1003 of agricultural waste are digested annually. The manure (with a density of 1 t/m3) has a DM of 10%, an OM/DM of 80% and a biogas yield of 0.25 m3/kg Om. The organic waste (with a density of 0.8 t/m3) has DM of 30%, an OM/DM of 70% and a biogas yield of 0.55 m3/kg Om.

Biogas production (m3/yr) = [(1000 x 1) (t manure/yr) x 10% x 80% x 0.25 x1000] + [(100 x 0.8) (t waste/yr) x 30% x 70% x 0.55 x 1000]

= 20000 + 9240

= 29240 m3/yr.

In order to determine the volume of a biogas digester, the following parameters needs to be considered. The amount of manure and co-substrate, the retention time (days) and the number of days in a year is calculated as follows/34/:

Digester volume (m3) = [manure (m3/yr) + co-substrate (m3/yr)] x $\boldsymbol{Retention\ time}$ **(**$\boldsymbol{days}$**) 365.** (2)

For example, 1000 m3 of cattle manure and 100 m3 of agricultural waste are annually digested with a retention time of 28 days. The volume of the digester is calculated as follows:

The digester volume = (1000 + 100) x (28/365) = 84.4 m3

The post digester storage can also be calculated as follows:

Size of storage (m3) = <u>Animal substrate (m3/yr) x required time (months)</u>
12 – Size of digester. (3)

For example, 1000 m3 of cattle manure and 100 agricultural wastes are digested annually with a retention time of 28 days. A storage time of two months is required.

The size of the post digester storage = (1000 + 100) x (2/12) - 84.4 = 99m3

Biogas can be stored in an external gas bag or a foil that cover the silo. When the biogas is consistently used in a CHP plant, 20-50% storage is enough for the storage or even less in real practice/34/.

Size of biogas storage (m3) = Daily biogas production (m3/day) x 20%

For example, a biogas production of 100000 m3/yr. means 274 m3/day.

This requires a biogas storage of 274 x 20% = 54.8m3

But when a foil is used, the diameter can be calculated as follows:

Diameter of digester (m) = 2 x √ $Volume\ of\ digester\ m2\ Height\ of\ digester\ (m)$ x **3.14.** (4)

For example, a digester of 84.4 m3 capacity is 2 m high.

The diameter = 2 x √ 84.4 2 x 3.14 = 2 x 3.7 = 7.4m

3.6 Biogas Engines

Biogas engines are specifically designed to operate on different types of biogas. These gas engines are linked to an alternator in order to produce electricity at high efficiency. High efficiency electricity production enables the end user to maximize the electrical output from the biogas and hence optimize the economic performance of the anaerobic digestion plant. Some gas engines with different levels of power output and electrical/thermal efficiency characteristics are /34/:

- 249-330kWe – Type 2
- 499-1,065kWe – Type 3
- 844-1189kWe – Type 4
- 1,600-3,000kWe – Type 6

3.7 Biogas CHP

Biologically derived gases can be utilized in biogas engines to generate renewable power via cogeneration in the form of electricity and heat. The electricity can be used to power the surrounding equipment or exported to the national grid /34/.

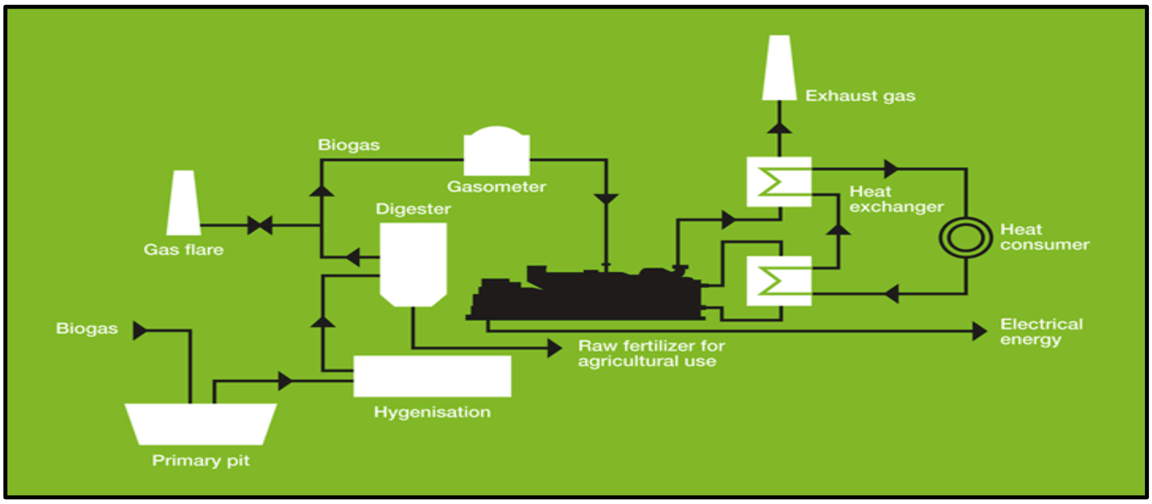

Figure 12. Biogas engine/38/

Low grade heat from the cooling circuits of the gas engine, typically available as hot water on a 70/90°C flow/return basis. For anaerobic digestion plants that are using a CHP engine, there are two key types of heat; the low grade heat is typically used to heat the digester tanks to the optimum temperature for the biological system. Mesophilic anaerobic digesters typically operate at 35-40°C. Thermophilic anaerobic digesters typically operate at a higher temperature between 49-60°C and hence have a higher heating requirement/34/.

High temperature exhaust gas heat can either be used directly into a drier, waste heat boiler or organic Rankine cycle unit. Alternatively it can be converted into hot water using a shell and tube exhaust gas heat exchanger to supplement the heat from the engine cooling systems/34/.

Waste heat boilers produce steam typically at 8-15bar. Driers may be useful to reduce the moisture content of the digestion to assist in reducing transportation costs. Organic Rankine cycle turbines are able to convert surplus waste heat into additional electrical output. The heat from the CHP engine can also be used to drive an absorption chiller to give a source of cooling, converting the system to a trigeneration plant/34/.

4 BIOENERGY IN KNUST

Case Study: Kwame Nkrumah University of Science and Technology

Kwame Nkrumah University of Science and Technology (KNUST) is an institution in Ghana with a student population of 39,990. It is situated approximately on a sixteen (16) square kilometre campus. The university has six (6) colleges namely College of Agricultural and Natural Resources, Engineering, Science, Arts and Built Environment, Humanities and Social Science, Health Science. College of Agricultural and Natural Resources consists of three (3) faculties namely, Agricultural, Natural Resources and Forest Resource Technology and five (5) research centres.

The faculty of Agriculture consists of five (5) departments where the Animal Science department can be found. The Animal Science department has a student population of hundred and thirty (130) and staff population 65 including lecturers and all other workers. The department has a farm which operates in both crops and animals. The size of the farm is about 40469m^2 which has various structures including farm house, lecture halls and laboratories, offices, animal houses, slaughter house and meteorological service post and, library. Below are some pictures of the animal farm.

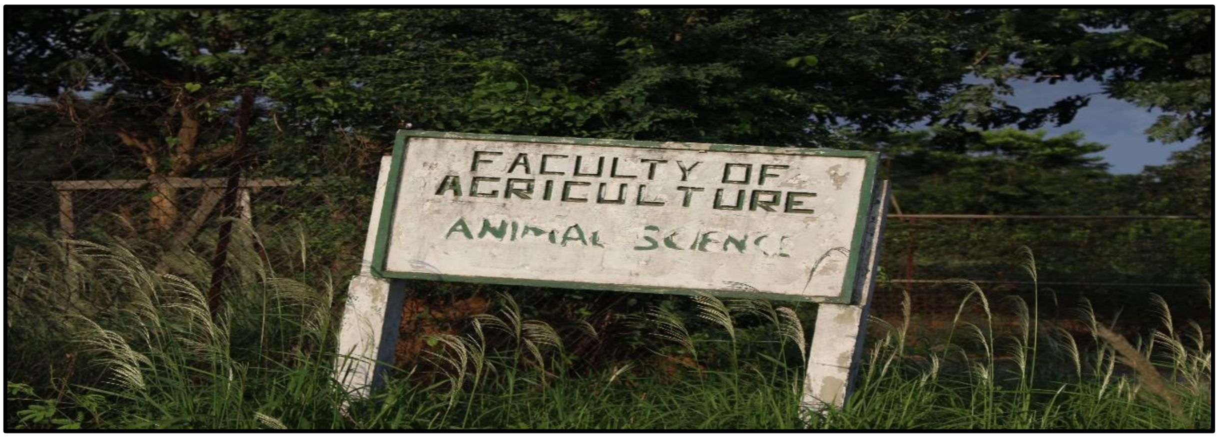

Figure 13. Department sign post.

Figure 14. Poultry project with Akate farms.

Figure 15. Cows relaxing.

Figure 16. Cross section of farm house.

Figure 17. Offices and laboratories and lecture halls.

Figure 18. Grazing field.

Figure 19. Slaughter house.

4.1 Biogas Analysis for Case Study.

The biogas analysis was done based on the data and information that was gathered from the school farm. The formula use to determine the biogas yield are used

4.1.1 Supply Chain of Feedstock

The area where the plant is located is about 150 to 200 meters away from the farms. Thus, the cleaners are responsible for collecting and transporting the material to the site using a small van truck.

Table 3. Percentage of Organic and Dry Matter with Biogas Potential Range/34/.

FEEDSTOCK	DRY MATTER (DM %)	ORGANIC MATTER (OM %)	BIOGAS YIELD(M^3/T ODM)
Cow manure	7-15	65-85	200-400
Pig manure	3-13	65-85	350-550
Goat manure	5-12	65-85	120-350
Sheep manure	5-12	65-85	120-350
Chicken manure	10-20	70-80	350-550
Rice straw	10	75-90	120-350

maize	10	85-91	120-350

4.1.2 Biogas Production from Crop Residues

Types of crops residue and their biogas yield are presented in the Table 4.

Table 4.Crop Residue and Their Biogas Yield

CROP	PRODUC-DUC-TION	RPR	CALCULAT-ED RESIDUE GENERAT-ED(T)[A]	DRY MATTER CONTENT (DM%)	OR-GANIC MAT-TER CON-TENT (OM%)	BIO-GAS YIELD FAC-TOR (M^3/T)	BIOGAS YIELD (M^3)
Maize husk	1564	1.30	2033.2	10	85	268	46316.3
Rice straw	1038	1.5	1557	10	80	264	32883.8
Total crop residue for biogas yield							79200.14

The total biogas production potential for both animal manure and crop residue are:

Total biogas production = animal manure production + crop residue production

$$= 3750272.8 + 79200.14$$

$$= 3829472.94$$

The equation below can be used to calculate the electricity generation potential of the calculated biogas yield /30/. The amount of methane content should be about 60%. /30/

$$P_e = \frac{fCH_4 * HvCH_4 * B_{igas} * \eta_e}{3.6 * 10^{6MJ}{}_{GWh}} \quad (5)$$

Where:

P_e = the potential for electricity generation (GWh/yr)

B_{igas} = the total biogas production ,m^3/yr.

fCH_4 = the faction of CH_4 in the biogas mix

ηe = the efficiency for the electricity generation system %

H_VCH4 = the heat value of CH_4(39.0MJ/m^3)

The conversation fraction from MJ to GWh is 3.6*10.

Biogas electricity has an efficiency of 25% to 30% ,and for this project 29% is used as its efficiency.

$$P_e = \frac{0.6*39.0MJ*3829472.94*0.29}{3.6*10^{6MJ}\ GWh}$$

$$P_e = 7.2GWh/yr.$$

The formula for calculating the biogas production is

Biogas production (m3/yr) = [Manure (t/yr) x DMm x OMm x (m3 biogas/kg OMm) x 100] + [Co-substrate x DMcs x $OMcs\ DMcs$ x (m3biogas/kg OMcs) x 1000].

The table below shows the biogas production in a year and the biogas yield factor. These calculations were based on the number of production stock. But the heat values are neglected due to the fact that the biogas is used to power engine for generating electricity.

Table 5. Knust Farm Biogas Yield Potential from Animal Manure.

LIVESTOCK SPECIES	PRODUCTION STOCKS[A] (1000 HEAD)	DRY DUNG OUTPUT (KGH-1D1)B	TOTAL ANNUAL DUNG OUTPUT (TONES)	DRY MATTER CONTENT (DM %)	ORGANIC MATTER CONTENT (OM %)	BIOGAS YIELD FACTOR (M3/T)	BIOGAS YIELD (M3)
Cattle	150	1.8	98550	10	80	300	2365200
Sheep	72	0.4	10512	10	80	235	197625.6
Goats	64	0.4	9344	10	80	235	175667.2
Pig	42	0.8	12264	10	90	500	551880
Chickens	500	0.06	10950	0.15	0.8	350	459900
Total manure biogas yield (m^3/yr)						3750272.8	

The biogas yield factor is taken from /30/ and the stocks and dung output is from/31/

4.1.3 System Description

The plant is made of a digester where the feedstock is kept for some number of days to digest and produce biogas. The biogas is stored in a storing tank if the biogas cannot be used instantly. The biogas engine is coupled to a generator and the heat is channelled through a pipe to turn a steam turbine which is used to generate electricity and excess heat for CHP. The excess heat is used for the digester to keep the required temperature for the processing of gas. Insulators are used to insulate the digester to maintain a constant temperature. Then, the pumps are used for pumping the feedstock. The pipe is used for the passage of feedstock from the tank to the digester and also used for the transportation of steam from one part of the system to the other. Furthermore, the mixer is used for mixing the feedstock in the digester, in order not to allow heavy solid particles to settle at the bottom of the digester. However, the feedstock is pre-mixed with the substrate to get the right ratio before pumping it into the digester. Also, a feedstock grinder is used to grind the residue to smaller particles before it is been fed into the premixing tank/34/.

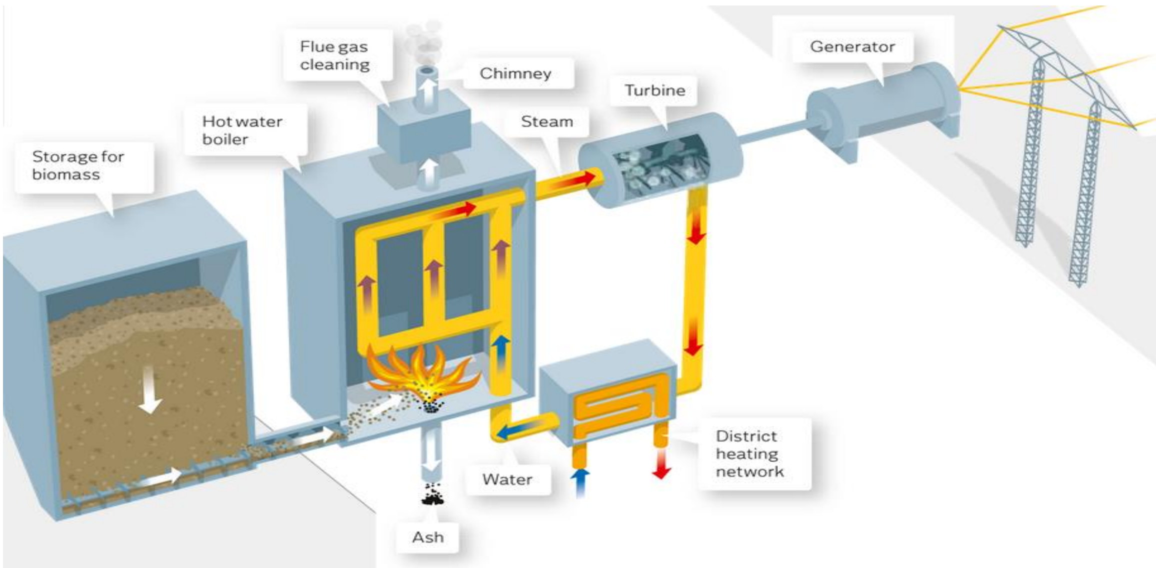

Figure 20: biogas plant showing various stages and parts/37/

The plant operation condition presented in Table 6.

Table 6: Plant operation conditions/34/.

Operation parameter	Typical value
Temperature (mesophilic)	(30-40)
Ph	7-8
Retention time	25-40 days
Feeding rate	16-18tons/day
Methane content	60-70%

4.1.4 Energy Demand Analysis of KNUST Animal Farm

The energy demand of KNUST Animal Science Department will be determined using the daily and monthly energy consumption in Ghana to get an average consumption. The monthly consumption of the department has been taken into consideration where the data of electricity consumption has been recorded from the meter reading of the department and the amount of money paid by the department every month to the electricity company of Ghana.

The electricity usage at the department varies daily due to the activities, equipment's and machines, also blackouts.

The total energy consumption in kWh is 7034.1, which is equal to the amount per energy tariff of Electricity Company of Ghana.

The table below shows the monthly consumption and bills payable by the department from 1st January- 30th September, 2017

Table 7: Monthly Consumption and Bills Payable

MONTH	AVERAGE DAILY CONSUMPTION IN A MONTH KW/H	MONTHLY CONSUMPTION KW/H	BILLS PAYABLE
January	22.5	697.5	1307.2
February	24.6	688.8	1290.9
March	26.5	821.5	1539.6
April	21.2	636	1191.9
May	26.1	809	1516.2
June	28.3	849	1591
July	27.4	849.4	1591.9
August	29.9	926.9	1737.2
September	25.2	756	1416.9
Total	7034.1		

From Table 7, it can be seen that by adding up all the monthly consumption we have 7034.1kW/h for a period of nine months and the power consumption has been between 20-30kW/h for the Animal Science Department. It is best to know the annual consumption so as to be able to calculate the annual consumption of electricity. It is therefore concluded that the consumption for the rest of the October November and will be estimated at `24.8, 26.7 and 20.1. The reason for December being 20.1 is because the activities of the department will reduce since the students will be on Christmas break so there will be no lectures and practical’s for students and all staff and other workers will be off campus.

Thus, we have 768.8 for October, 801 for November and 623.1for December. The bills for the other months will be 768.8, 801and 623.1 respectively.

Therefore, the total power consumption for the year is 7034.1+2192.9 = 9227KW/h or 0.009227GW/h so as the total bill for the year will also be 9227 Ghana Cedis.

In order to know the quantity of biogas needed to generate the annual energy demand, the formulas used to calculate the department biogas electricity potential is used but making the total biogas produce the subject/30,34/.

$$\text{The amount of biogas needed } (B_{igas}) = \frac{Pe*3.6*10^{6}\ MJ/GWh}{CH4*HvCH4*\eta e} \qquad (6)$$

$$B_{igas} = \frac{0.009227\text{GW/h} * 3.6 * 10^{6}\ MJ/GWh}{0.6*39.0MJ*0.29} = \frac{33217.2}{6.552} = 5069.78\text{m}^{3}$$

In order to get the CHP capacity, the formula below is used

$$\text{CHP capacity (KWe)} = \frac{fCH4*HvCH4*B_{igas}*\eta e}{Operaton\ h\ yr * 3.6\ MJ\ KWh}$$

$$\text{CHP capacity (KWe)} = \frac{0.6*39*5069.78*0.29}{7500*3.6} = \frac{33217.2}{27000} = 1.27\text{KWe}$$

The percentage of biogas used from the total biogas potential is:

$$\text{Estimated biogas to be used} = \frac{5069.78}{3829472.94} \times 100 = 0.013\% \qquad (7)$$

Therefore 0.013% of each feedstock is needed to generate the energy for the Department of Animal Science of Kwame Nkrumah University of Science and Technology.

4.1.5 Investment Cost Analysis

The table below shows the investment cost calculation for the digestion of feedstock and the energy generation for farm.

Table 8. Cost Estimation for 1.27 kw Biogas Plant

Biomass plant capacity	1.27 kW
Annual biogas production	5069.78 m3
Electricity production per year	9227 kWh
Farm’s annual electricity consumption	7034.1 kWh
Total cost of project	EUR 12000
Annual O&M cost	EUR 1050
Annual electricity bill of farm (Previous)	EUR 2636.65
Annual gain from project	2636.65-1050 = EUR 1586.65
Payback period (years)	12000/1586.65 = 7.5 YEARS

4.2 Benefits of Biogas for KNUST Farm

Greenhouse gas emission effect will be reduced since there will be no burning associated with fossil fuels as well as the reduction of CO_2 in the atmosphere which could tackle global warming /34/.

The department is currently having problems with a constant flow of electricity so in this case it will help the department to get access to constant electricity power which would be also extended to the other parts of the farm.

The department could also be able to save most money used for paying bills and can channel into other usage which could benefit the students.

4.3 Socio-Economic Benefits

Biogas production could have a direct impact on rural urban development poverty reduction/34/.

It could improve rural livelihoods by providing new income opportunities to families and communities growing biomass, or through direct employment.

Using biomass resources in unconnected power generation units could insulate poor rural households from energy price fluctuations, allowing for an independent electricity source.

5 CONCLUSION

This study critically focuses on how biomass can be used to produce energy and its benefit. The study shows that a variety of biomass resources exist in the KNUST Animal Science Department, and that there is also an immense opportunity for their conversion to energy using different biomass conversion technologies that are currently available. It was seen that the annual biogas production would be enough for the department's energy consumption. This study has been a purely mathematical evaluation of data derived from field work. The Department farm has enough supply of crop and animal biomass resource which is a potentially significant source for energy production. With the resources in the school farm, there is indication that some of the crop and animal biomass are already exploited but greater amounts are treated as waste and remain untapped. The implication is that every department in the university or the university as a whole can take advantage of the availability of the raw material to maximize its potential.

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