BIOGAS FROM WASTE –TO-ENERGY; GREEN POWER AND CLEAN ENVIRONMENT FOR BOLE LEMI INDUSTRIAL ZONE.

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the requirements for the Degree of Master of Science in Power System Engineering

By

FIREHIWOT GIRMA DIRES
(GSE/1999/04)

Advisor: - FREHIWOT WOLDEHANNA (PhD.)

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OFTECHNOLOGY (AAiT)

SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

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Addis Ababa Institute of Technology (AAiT)

Department of Electrical and Computer Engineering

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DECLARATION

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

Name: FIREHIWOT GIRMA
Signature: _____________
Place: Addis Ababa
Date of submission: February, 2017

This thesis work has been submitted for examination with my approval as a university advisor.

Dr. FREHIWOT WOLDEHANNA	_________________
Advisor's Name	Signature

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CONTENT

Abstract

The current model for electricity generation and distribution in Ethiopia is dominated by centralized power plants typically based on hydro power resource. Most of the substation in the country are old and needs upgrading. The construction of high rise buildings and industrial zones create an overloading on the existing substations, this problem can be solved by constructing new substation, upgrading old ones and using distributed generation (DG) systems. DG technologies often consist of modular and renewable-energy generators. By connecting to local distribution networks, energy is produced and consumed closer to the source of generation. This research is about using the waste to energy technology to generate green power for BOLE LEMI INDUSTRIAL ZONE (BLIZ) and a clean environment for the surrounding. A DG system is designed using biogas from the waste disposal pond KOTEBE Sewage Treatment plant (KSTP) at a close proximity ,around 0.3km ,from the BLIZ and a waste from wet room of the industrial shades as a renewable resource. It is discovered that a total of 66.45MWh/day electrical energy can be generated from the two resources and using only the resource from the KSTP a total of 36.057MWh/day electrical energy can be generated. Two methods of connection of the DG system is studied, HOMER optimization and RETscreen clean energy software are used to select the method of connection. And the waste to energy DG system connected to the grid is found to be economically feasible with LCOE $0.023/kWh .The DG system increases the reliability of the power system for the Bole Lemi substation (BLSS) and as a result of the biogas generation the odor pollution will be reduced and the environment for the surrounding will be clean.

Key words: Waste to Energy, Biogas, Distributed Generation, Industry zone, Grid Connection, Odor Pollution.

List of Figures

List of tables

List of Abbreviations

AAWSA	Addis Ababa Water and Sewerage Authority.
AMPTS	Automated Methane Potential Test System
BLIZ	Bole Lemi Industrial Zone
BLSS	Bole Lemi Substation
BV	Biogas Volume
CHP	Combined Heat and Power
DG	Distributed Generation
DEOR	Draft Energy Operation Regulation
EEU	Ethiopian Electric Utility
EBCS	Ethiopian Building Code of Standards
EEP	Ethiopian Electric Power
EEA	Ethiopian Energy Authority
EE	Electrical Efficiency

EIA	Environmental impact analysis
FDRE	Federal Democratic Republic of Ethiopia
FIT	Feed in Tariff Policy
FMOI	Federal Ministry of Industry
HOMER	Hybrid Optimization Model of Electric Renewable
IPP	Independent Power Producer
KSTP	KOTEBE Sewage Treatment plant
LCOE	Levelized Cost Of Energy
LCV	Lower Calorific Value
LDC	Load Dispatch Center
LHV	Lower Heating Value
NPC	Net Present Cost
NPV	Net Present Value
O&M	Operation and Maintenance
RE	Renewable Energy
TE	Thermal Efficiency
TS	Total Solid
VS	Volatile Solid

1. BACKGROUND AND INTRODUCTION

1.1. Introduction

The current model for electricity generation and distribution in Ethiopia is dominated by centralized power plants typically based on hydro power resource. Centralized power models require distribution from the center to outlying consumers. Current substations can be anywhere from tens to hundreds of miles away from the actual users of the power generated. This requires transmission across the distance. More over the construction of high rise buildings, condominiums, industrial zones in the city, and the increased energy demand of the population in the country creates a big traffic in the existing transmission lines and substations are usually overloaded during peak load times, this causes power fluctuations and generally the power system is becoming unreliable.

Apart from increasing the number of substations and upgrading the distribution networks these problems can be mediated through Distributed Generation (DG) systems. DG technologies often consist of modular and renewable-energy generators, and they offer a number of potential benefits. By connecting to local distribution networks, energy is produced and consumed closer to the source of generation, negating the need to transport it over long distances thus improving energy efficiency. Examples of distributed generation include solar, wind, biomass and Cogeneration. This research is about using biogas as a renewable resource to generate electrical energy for Bole Lemi Industrial Zone (BLIZ).

1.2. Background

1.2.1. Bole-Lemi Industrial Zone (BLIZ)

The Ethiopian government is building new industrial mega-zone named BOLE LEMI INDUSTRIAL ZONE that has successfully attracted foreign investors with manufacturing plants moving from China, India, and the rest of the world.

The BLIZ located at the outskirt of Addis Ababa is the first industrial hub for export-oriented manufacturers and is being constructed with the aim of supporting the government's bid to deliver fast economic growth. This industrial zone is located at 8^{o} 58” N 38^{0}51”E 2270m .

According to the Federal Ministry of Industry (FMOI) The BLIZ phase one has already been finalized. It occupies 156 hectares of land and is expected to create employment for around 28000 people. It consists of twenty industrial shades, ten of them with area of 10,000m^2 and the other ten shades are covering area of 5000m^2.Phase two site covers 186 hectares of land with focus mainly on the textile and leather sectors. Noting that industrial parks are important to accelerate the industrialization process of the Growth and Transformation Plan, the government is undertaking various activities to realize the development of industrial zones.

The ratification of the new proclamation on industrial parks and the improvement of the earlier investment law are among the activities taken by the government to develop industrial parks. Furthermore, the government had also attempted to mobilize euro bonds to raise capital for the manufacturing sector, especially for the energy and industry sector [1].

1.2.2. *KOTEBE Sewage Treatment plant (KSTP)*

The KOTEBE sewage treatment plant is located at 0.3KM from BLIZ with an approximate coverage area of 180 hectares. The sludge disposal facility at KOTEBE has the capacity to treat approximately150,000 m^3/year and consists of 20 drying beds and 10 lagoons. The sludge lagoons are used in the rainy season to store sludge until the dry season. From the sludge lagoons the sludge can be pumped to the drying beds. The treatment plant is set up to receive sludge from vacuum trucks that empty septic tanks [2].

The combination of huge energy demanding industrial shades with an availability of cheaper resource in immediate vicinity creates an ideal situation to apply research on the subject. That makes a welcome change from the two issues that have dominated the debate about energy in the past few decades: scarcity and concerns about the environment. Energy-efficiency potentials combined with renewable-energy sources provide an alternative energy that can be made accessible with currently available technologies.

1.3. **Problem Definition**

The upcoming manufacturing plants demand a great deal of sufficient and reliable energy to function properly and meet their target. The load demand will be an additional load for the existing substations in the surrounding, especially when all the factories start working in their full potential. In order to solve this current problem Ethiopian Electric Power (EEP) has constructed a mobile substation with a capacity of 50MVA power using 3.1km transmission line taped from KALITY I –KALITY North 132KV transmission line dedicated mainly for the industrial shades.

On the other hand, there is a cheap renewable energy resource, the biomass sewage sludge, at a distance of 0.3Km from the industrial zone left in waste disposal ponds to evaporate to the environment and surge to the surface or underground water. These evaporated wastes create unpleasant odor to the surrounding and the accumulation of waste on large waste disposal sites are thought to have caused a doubling of the atmospheric concentration of methane to the present level. This may have an effect on public health and environmental pollution. Moreover, as methane is part of the chemical processes in the atmosphere and is also a powerful greenhouse gas (about 22 times as powerful as carbon dioxide, CO_2), the gas is a contributor to the greenhouse effect.

Different researches had been carried out on the supply of energy for different industries from power generators working by fossil fuels. This research is all about the generation of green energy from biogas using waste-to-energy technology for a clean environment at the surrounding.

1.4. **Objectives**

The general objectives of this research are:-

- To study the possibility of applying a waste-to-energy technology for the production of electrical energy to meet the demand of the nearby industrial zone called Bole Lemi (BLIZ), using biogas from sewage sludge in the waste disposal ponds of KOTEBE Sewage Treatment plant (KSTP) and to understand the creation of clean and non-polluted environment for the surrounding, by converting the waste disposed to useful energy.

The Specific objectives are:-

- To investigate the potential of the resource available for the production of biogas.

- To determine the type of anaerobic digester for the resource available.
- To estimate the total energy generating capacity of the biogas collected from the resource.
- To estimate total electrical power required by the industrial shades.
- To determine biogas plant layout and the size of digesters including selection of the components such as the digester and generator.
- To investigate the means for removing the odor from the waste.

1.5. Methodology

To achieve the above specific objectives the following methods are adopted.

- The data on the amount of waste disposed every day in the waste disposal ponds is investigated form Addis Ababa Water and Sewerage Authority (AAWSA).
- The anaerobic digestion process is studied for the assessment of the renewable energy generated from the organic waste.
- The biogas volume production is estimated from the Organic Waste Quantity, Total solid (TS) content, and Volatile solid (VS) content.
- Analysis of demanded load by the factories and the amount of power that can be extracted from the existing resource is made.
- Analysis of the site available for the construction and erection of the biogas plant is made.
- The Biogas power plant is finally modeled.

2. LITERATURE REVIEW

2.1. Biogas and Anaerobic Digestion

Biogas is a combustible mixture of gases. It consists mainly of methane (CH_4) and carbon dioxide (CO_2) and is formed from the anaerobic bacteria decomposition of organic compounds, i.e. without oxygen. The gases formed are the waste products of the respiration of these decomposer microorganisms and the composition of the gases depends on the substance that is being decomposed [3].

Anaerobic digestion is a series of biological processes that use a diverse population of bacteria to break down organic materials in to biogas, primarily methane, and a combination of solid and liquid effluent, the digestate, in the absence of oxygen. Anaerobic digestion is used in concentrated animal feeding operations as a way to treat livestock manure, in wastewater treatment plants to treat sewage, and it occurs in all municipal solid waste landfills as the organic waste breaks down.

The end product biogas is composed of Methane (CH_4, Typically 60-70% by volume) and carbon dioxide (CO_2, 30-40% by volume) as well as small amounts of H_2S and other trace gases [4]. Biogas can be combusted to generate electricity and heat or processed in to renewable natural gas and transportation fuel.

Apart from biogas generation the commonly recognized benefits of anaerobic digestion are:-

- Reducing odder mission, which improves air quality.
- Protecting water quality by reducing pathogens associated with manure to enter surface or ground water.
- Improves manure nutrients availability to plants.

2.2. Measuring Biogas Potential.

Many methods based on product formation measuring biogas have been published over the years. All carry out the basic principle, however, the technical approaches and experimental setups vary significantly. There exist many differences in the pre-treatment of sample, the incubation process and the gas measurement method [5]. The biogas production can be measured as an increase of volume under constant pressure (volumetric methods), measuring the increase in pressure in constant volume (manometric methods), or the measurement of methane formation by gas chromatography [6]. All these procedures require expensive laboratory equipment, such as gas chromatography, also the biogas produced and methane content can only be measured manually and periodically with gas tight syringes,

The methane potential is expressed in terms of standard temperature and pressure (STP) ml CH_4 per 1 g of VS added (ml CH_4 / g VS) [5].

Researchers have tried to discover the biogas potential of a specific substrate (feed stock) by setting up a batch digestion tests. Two literatures reported that the biogas samples are examined by gas chromatography to determine the CH_4 and CO_2 content based on the PH, TS and VS of sewage sludge which were determined according to standard methods. The literatures also reported that the biogas production rate is mainly dependent on the type of substrate, temperature, feedstock availability, and the retention time, the biogas production is slow at the beginning and end period of observation, this is predicted due to the biogas production rate in batch condition is directly corresponds to specific growth rate of Methanogenic bacteria in the bio-digester. But the most vital reason for a choice is the feedstock availability [7] , [8] . The biogas potential of feedstock also depends on the gas yield per kilogram of Total Volatile solid (TVS) present.

The methane potential of a sewage sludge can also be discovered by using automated methane potential test system (AMPTS) [9]. Batch digestion tests were performed to analyze two different types of sludge as inoculums. The experiments were conducted using each inoculums with different inoculums to substrate ratio in terms of VS content and volume. The same substrate was used throughout all the experiments. The methane potential then calculated taking in consideration the grams of VS added in the substrate volume in each reactor, therefore expressed as Normal Liter per grams of volatile solids (L/g VS). The maximum methane potential of Reactor 1 and Reactor 2 in the 20 days of incubation was 0.29 L/g VS and 0.33 L/g VS respectively [9]. These results are in an average range compared to other literature results such as the gas yield and methane content for sewage sludge 310-740 L/kg TVS and the gas yield potential increases with the increase of retention time [10] , It is also reported that a methane potential of 606 L/Kg VS is discovered after 30 days of retention time [7].

2.3. **Anaerobic Digesters**

There are several designs of anaerobic digester available; the most appropriate for a particular site will depend on the waste handling system and the climate where the plant is located. The most commonly used designs are the covered anaerobic lagoon digester, the complete mix digester, the plug flow digester, and fixed dome digester [11] and [12].

The covered anaerobic lagoon consists of a pond-like earthen basin that is sealed with a flexible cover that captures the biogas .Anaerobic lagoons are used to treat influent with less than 3 percent solids; therefore they are best suited for systems that handle manure in a liquid form.

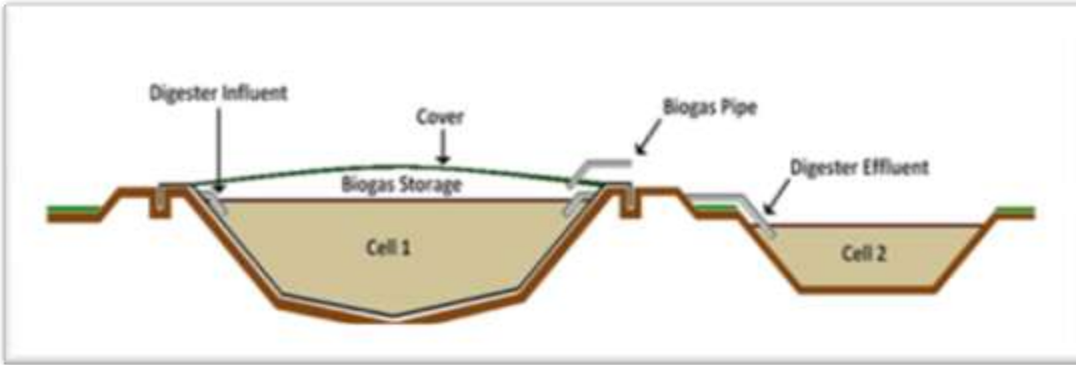


Figure 2-1; Anaerobic Lagoon Digester

Source: [13].

A complete mix digester (Figure 2-2) is an enclosed insulated tank, made of reinforced concrete, steel or fiberglass. Heating coils inside the tank circulate hot water in order to keep the operational temperature warm enough to maintain active anaerobic digester [12]. The contents are mixed with a mechanical, hydraulic, or gas mixing system. As the influent enters the digester, it displaces volume, causing an equal amount to flow out. The system uses a gas-tight cover (that can be flexible or rigid) to trap the biogas. The complete mix digester is best suited to process liquid manure that has 3-12 percent total solids.

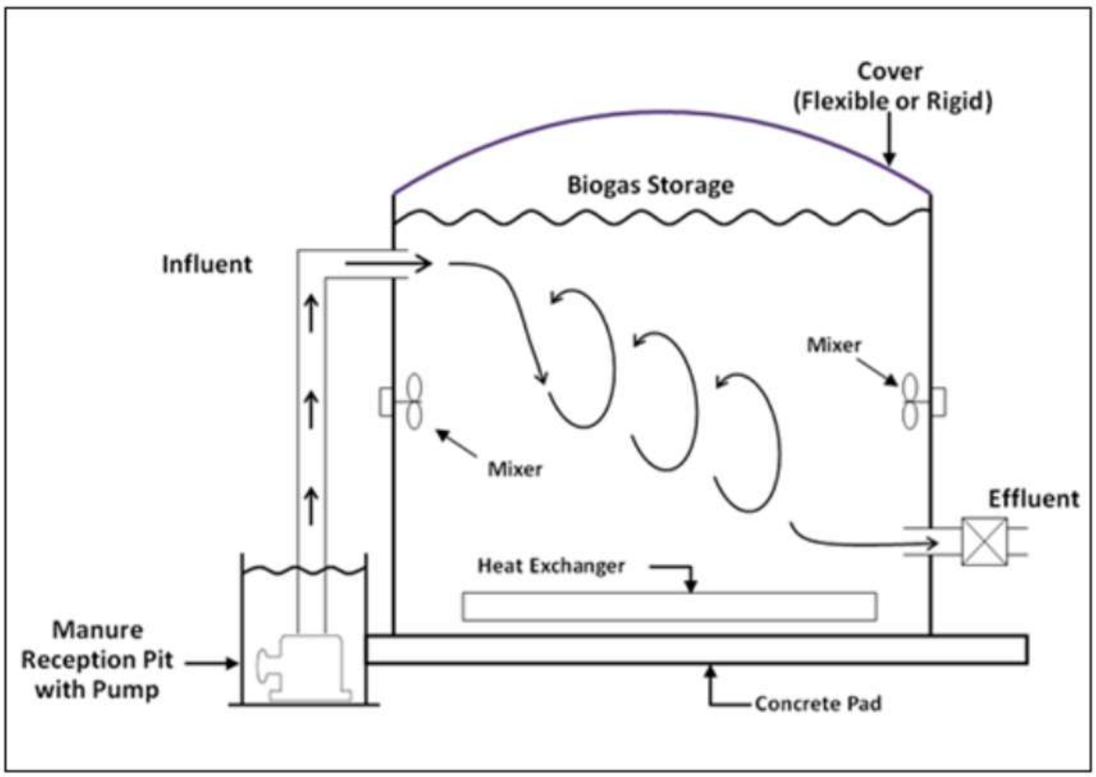


Figure 2-2 Complete Mix Digester

Source: [13].

A plug flow digester **(Figure 2-3)** is a long and narrow rectangular concrete tank with a flexible or rigid cover to capture the biogas. The tank is heated, insulated, and built partially or fully below the ground in order to limit heating requirements. The tank operates at the mesophilic range between 20and 40 degrees centigrade. The manure does not mix as it makes its way longitudinally through the digester. As new manure is added, it displaces an equal volume out, hence the name plug-flow, because the manure moves as a plug through the digester without mixing.

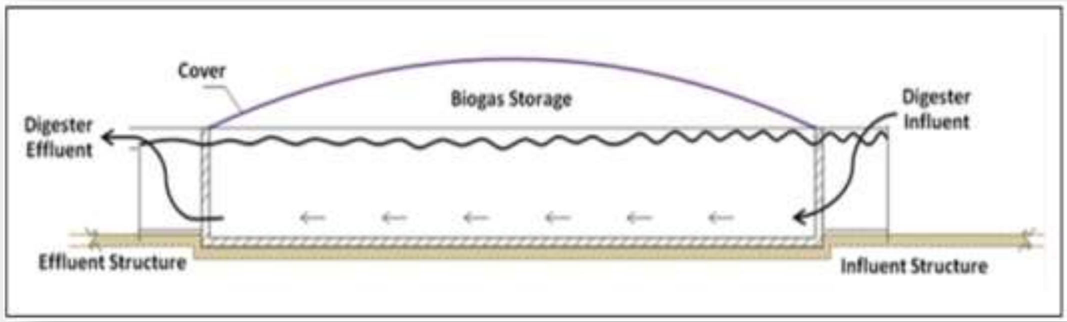


Figure 2-3; Plug flow digester

Source: [13].

The fixed-dome digester, fixed dome plant comprises of a closed dome-shaped digester with a rigid gasholder and displacement pit, also named ‘compensation tank’. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the Compensation tank [13].

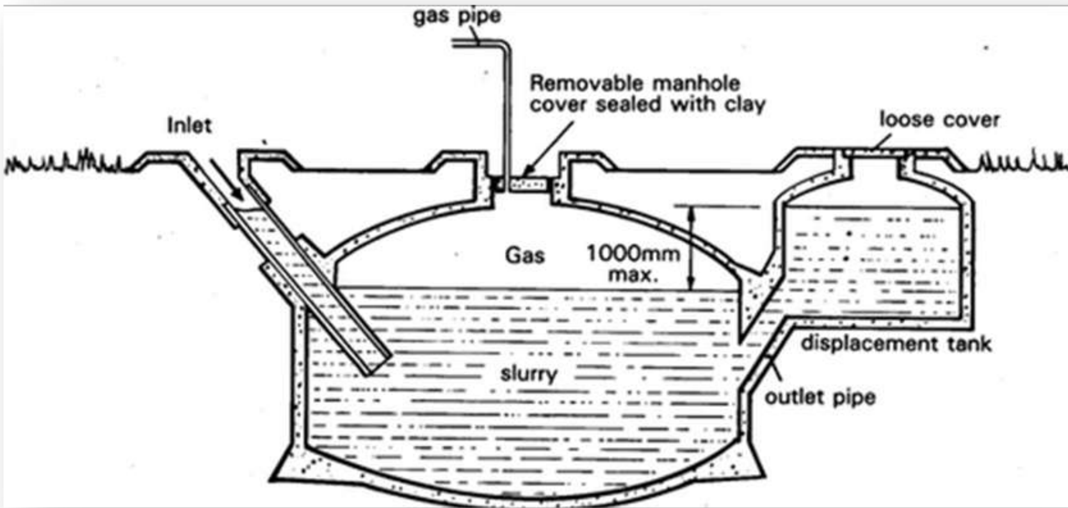


Figure 2-4 ;Fixed dome digester

Source: [13].

Several other digester types have also been constructed in recent years, such as induced blanket reactors, fixed film digesters and batch digesters. The selection of the right design of anaerobic digester will be mainly dependent on the type of resource, climate, and other limiting factors like, available space and initial investment cost.

2.4. Electrical Power Generation from Biogas

In most cases, biogas is used as fuel for combustion engines, which convert it to mechanical energy, powering an electric generator to produce electricity. Appropriate electric generators are available in all sizes. The technology is well known and maintenance is simple. In most cases, even universally available 3-phase electric motors can be converted into generators [14].

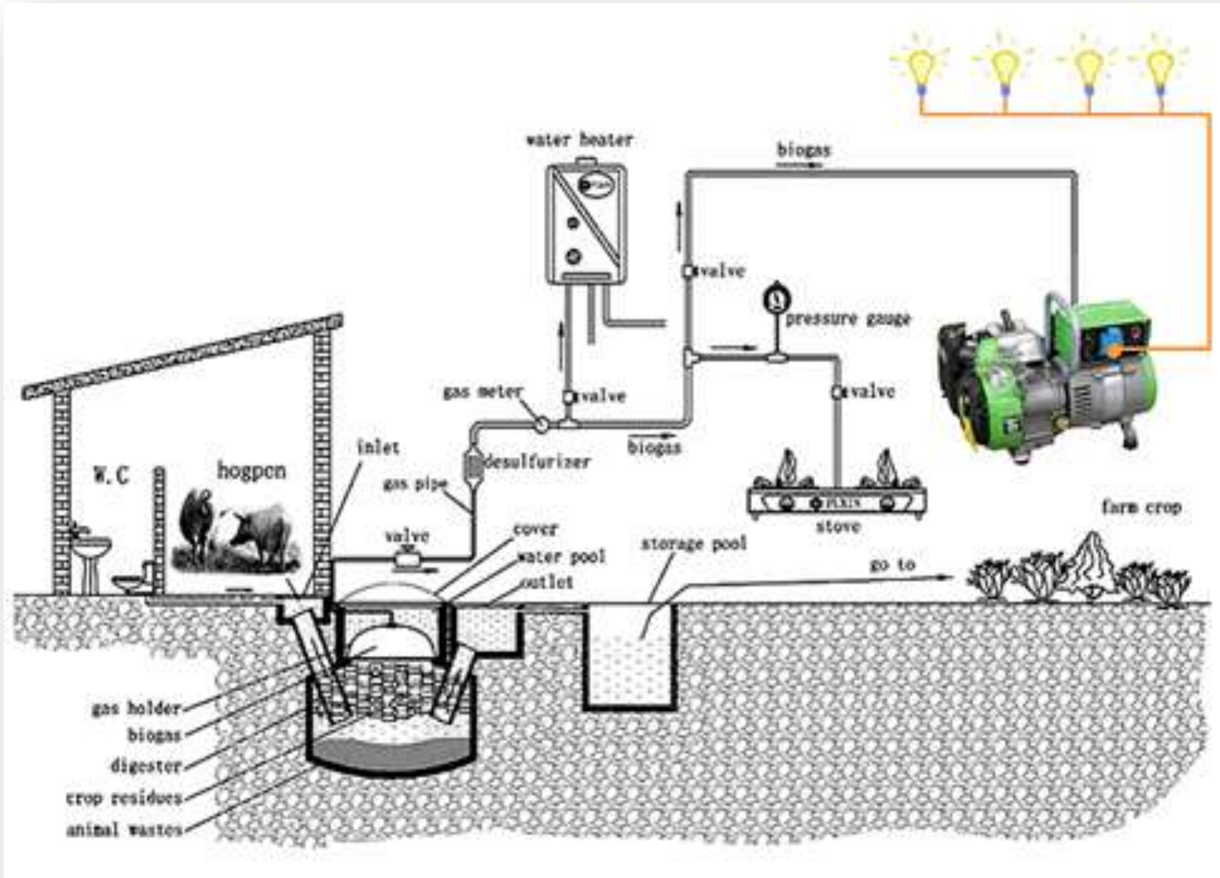


Figure 2-5: Schematic of a biogas plant used for power generation

Source: [6].

Electricity generated using biogas displaces generation at bigger power plants that may use other fuels such as coal which emits large quantities of greenhouse gases and several different types of pollutants. Thus, the use of biogas for electricity generation could contribute to a reduction of the emissions of greenhouse gases and air pollutants.

From a total quantity of sewage sludge that could produce a biogas volume of 7.82 thousand m^3 can be converted into 16.43MWh electricity and 21.13MWh of thermal energy by making use of specific assumptions of the lower calorific value (LCV) of biogas, 6 kWh/ m^3, the electrical efficiency (EE), evaluated at 35%, and the thermal efficiency (TE) fixed at 45% of the cogeneration engines [15].

Biogas plant produces high quality bio-fertilizers as well as electricity; the nutrients contained in the substrate are retained and more easily available to the plants, as the flow power of the liquid manure and its ammoniac content have increased, due to fermentation the unpleasant smell of liquid manure and organic wastes have disappeared, as the organic acids have been decomposed. The biogas plant is therefore useful to create odorless environment for the surrounding [16].

3. RESOURCE ASSESMENT AND SYSTEM SIZING

3.1. Resource Availability.

The sludge disposal facility at KSTP consists of 20 drying beds and 10 lagoons. According to AAWSA the lagoons or oxidation ponds are for sewerage directly coming through pips and the drying beds are used to receive sludge from vacuum trucks that empty septic tanks, As per the data collected from AAWSA the average amount of sludge disposed by vacuum truck is 1500m^3/day and the sewerage coming through pipes is 3000m^3/day. As the number of population in the city is increasing and the construction of condominiums is also increasing, the amount of sludge disposed will be expected to increase accordingly.

Since the water content of the sewage coming through pipe is nearly 99% and the volatile solid (VS) is very low, it will not be used as a biomass resource for this research.

The main and the first biomass resource for this research is the 1500m^3/day sludge disposed by vacuum truck.

The laboratory result for the KOTEBE and KALITY treatment plants as of 2008 is listed on Table 3.1.

Table 3-1 AAWSA KOTEBE and KALITY waste water treatment plant Raw sludge (night Soil quality) 2008.

Source: AAWSA

No	PARAMETER	UNIT	VALUE
1	Temperature	^oC	20
2	PH	-	7.8
3	Biochemical Oxygen demand (BOD) (5day)	mg/l	4800
4	Chemical oxygen demand(COD)	mg/l	37800
5	Total solid (TS)	mg/l	31500
6	Total dissolved solids (TDS)	mg/l	6480
7	Volatile solid (VS)	mg/l	18600
8	Settle able solids	ml/l	120
9	Ammonia	mg/l	2460
10	Phosphate	mg/l	2865

The second resource is the waste water collected from industrial wet rooms, and food preparation waste from canteens of each shade, excluding industrial wastes. The daily volume of this waste will be calculated from the total number of workers of each shade. As per the data collected from the FMOI the factories that leases the industrial shades with area of 10,000 m^2 are expected to open a job opportunity for an average number of 2000 people and shades with area of 5000m^2 are expected to open a job opportunity for an average number of 800 people. This makes a total of 28000 people for the 20 shades. The potential for the second resource will be calculated assuming the number of workers in the BLIZ will be equal to 28000 and using the data from Ethiopian building Code of Standards volume 9 (EBCS-9).

Sludge production per person per day

(S/p/day)= 0.15Litter ------------------------------------- *(EBCS-9)*

Water consumption per person per day for factory with canteen

(W/p/day) =45Litter ------------------------------------- *(EBCS-9)*

TP =Total number of workers (person) = 28000 ----------------------- *(Assumption)*

Total Volume of sludge per day

(S/day)= TP(S/p/day+ W/p/day)* --------------------------------- *(1)*

S/day =1264.2 m^3/ day -- *(2)*

The total amount of sludge available will be the sum of the S/day from the two resources which makes a total of **2764.2m^3/day.**

3.2. **Analysis of Energy Demand of the Industrial Shades.**

The BLIZ consists of 10 numbers of 10,000 m^2 shades and 10 numbers of other shades with area of 5000m^2. A total number of 20 shades are constructed on the 1st phase and according to the EMOI around 35 shades will be constructed on the 2nd phase.

A site survey has been made in order to estimate the total energy demand of the industrial zone. Most of the shades are garment and leather factories. And the power consumptions are expected to be in an acceptable range.

The power meter reading of only three shades can be collected during the site visit.

Table 3-2 : Real time power consumption of sample shades.

Factory	**Area of blocks**	**No of blocks**	**Power consumption**	**Daily Energy `consumption**
JAYJAY Garment Factory	10000 m^2	2	150kW with 30% load connection =500kW	=500kW*8hrs =4000kWh each
	5000m^2	1	90kW with 50% load connection =180kW	=90/0.5*8hrs =1440kWh
SHINTZ Garment Factory	10000m^2	1	450kW with 100% load connection	=450kW*8hrs =3600kWh

According to EMOI the type of manufacturers that leases the industrial shades are most of them garment factories and a small number of shoos factories. The power meter reading for the three sample factories is assumed to be the same for all the rest of the shades and for the purpose of estimation an average value of 483.3kW for the 10000m^2 shades and 180kW for the 5000m^2 shades is taken, considering 8hr/day of working time the average energy consumption will be 3866.7kWh and 1440kWh for the 10000m^2 and 5000m^2 shades respectively.

Therefore the total amount of energy demand each day can be calculated as:-

Total energy for the 20 shades (E)

$= (E_{av\,1000} + E_{av\,5000})*10 = 53067kWh$ -- (3)

Total Power required by the 20 shades (P) = E/daily working hour --------------- (4)

$P = 6,633.4kW$ -- (5)

3.3. **Analysis of the Biogas Potential of the Resource Available.**

3.3.1. Biology of Digestion

The most important thing to remember is that digestion is a biological process. The anaerobic bacteria responsible for digestion can't survive with even the slightest trace of oxygen. So, because of the oxygen in the manure mixture fed to the digester, there is a long period after loading before actual digestion takes place. During this initial "aerobic" period, traces of oxygen are used up by oxygen-loving bacteria, and large amounts of carbon dioxide (C02) are released. When oxygen disappears, the digestion process can begin. That process involves a series of reactions by several kinds of anaerobic bacteria feeding on the raw organic matter. As different kinds of these bacteria become active, the by-products of the first kind of bacteria provide the food for the other kind (Fig. 3.1). In the first stages of digestion, organic material which is digestible (fats, proteins and most starches) are broken down by acid producing bacteria into simple compounds. The acid bacteria are capable of rapid reproduction and are not very sensitive to changes in their environment. Their role is to excrete enzymes, liquefy the raw materials and convert the complex materials into simpler substances (especially volatile acids, which are low molecular weight organic acids. The most important volatile acid is acetic acid a very common by-product of all fat, starch and protein digestion. About 70% of the methane produced during fermentation comes from acetic acid [17].

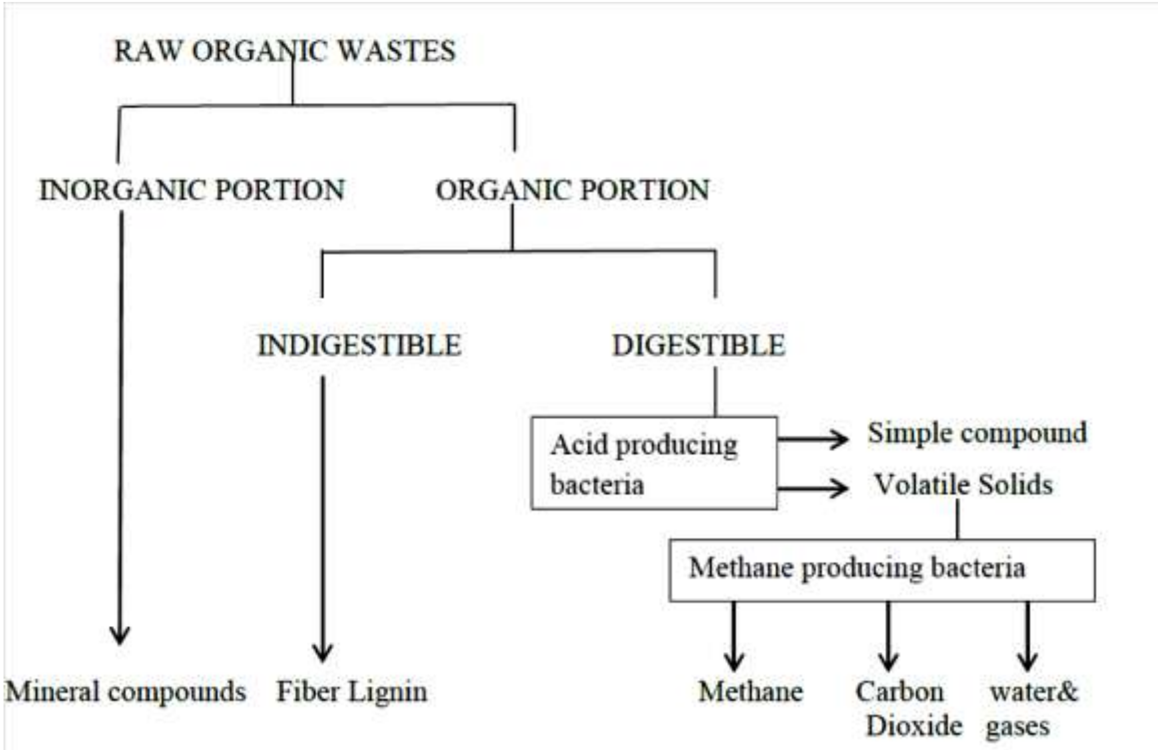


Figure 3-1 : The biological Break Down of wastes in the digester

Source: [17].

3.3.2. PH (potential of hydrogen) and the Well-Buffered Digester

The organisms involved in each phase of the digestion process are different and need different pH ranges to achieve an optimum environment to live in. Therefore equilibrium between production and consumption of acids must be established so bacteria can coexist inside the digester in appropriate conditions. The change in pH can be both an indicator, and the cause of process imbalance.

During the initial acid phase of digestion, which may last about two weeks, the pH may drop to 6 or lower, while a great deal of CO_2 is given off. This is followed by about three months of a slow decrease in acidity during which volatile acids and nitrogen compounds are digested, and ammonia compounds are formed (this ammonia becomes important when we consider the fertilizer value of sludge). As digestion proceeds, less CO_2 and more methane is produced and the pH rises slowly to about 7. As the mixture becomes less acid, methane fermentation takes over. The pH then rises above the neutral point (pH = 7), to between pH 7.5 and 8.5. After this point, the mixture becomes well buffered; that is, even when large amounts of acid or alkali are added, the mixture will adjust to stabilize itself at pH 7.5 to 8.5 [17].

Once the mixture has become well buffered, it is possible to add small amounts of raw material periodically and maintain a constant supply of gas and sludge (continuous load digesters). If the digester does not been fed regularly, enzymes begin to accumulate, organic solids become exhausted and methane production ceases.

After digestion has stabilized, the pH should remain around 8.0 to 8.5. The ideal pH values of effluent in sewage treatment plants is 7 to 7.5, and these values are usually given as the best pH range for digesters in general [17].

3.3.3. Daily biogas yield from the resource available.

The amount of biogas generated each day BV [m^3 gas/d], is calculated on the basis of the Specific gas yield of the substrate and the daily substrate input S/day. The calculation can be based on volatile solid content, suspended solid content or standard gas yield value per livestock [10]. In order to calculate and estimate the biogas potential of the substrate available, the findings of the different researches reviewed is be used.

As it is discussed in the previous chapter different researchers discover different biogas potential of sewerage sludge with an acceptable range from 290 -740L /Kg of VS with 20-30days of retention time. For this research an average value of 515L/Kg of VS with retention time of 20 days is being used to calculate the daily biogas yield of the two types of resources available.

The two resources available will be treated separately with different reactors and their daily biogas yield also be calculated separately as follows.

1. *KSTP Raw sludge*

   Daily sludge disposed at the site (S/day) = 1500m^3/ day (AAWSA)

   Volatile solid content (VS mg/L) = 18600 mg/L = 18.6 kg/m^3 (table 3.2, AAWSA)

   Biogas volume per kg of volatile solid (BV L/kg of VS) = 515 L/Kg =0.515 m^3/kg (conversion factor 1Litter =0.001 m^3 and 1 kg=1000000 mg)

   *BV/day=S/day * VS * BV/Kg VS* --- *(6)*

   Substituting values

   BV/day =14365.5 m^3/day--- *(7)*

2. *Waste water from industries wet room canteen.(future value)*

   S/day =1264.2 m^3/ day --- *(from eq.2)*

   VS =18.6kg/m^3 ......the same amount as the sewerage sludge is taken.

   BV /kg of VS= 515L/kg=0.515m^3/kg ---------------------------- *(average value)*

   *BV/day =S/day *VS*BV/kg VS*

   = 12109.8 m^3/day --- *(8)*

   The amount of BV from the second source can be increased by using co-digestion of the wet room waste and the food preparation wastes from the industrial shades.

   Therefore *Total BV/day*

   = 14365.5m^3/day + 12109.8m^3/day----------------------------------- (9)

$= 26{,}475.3m^3/day$-- (10)

A total amount of ***26,475.3m³*** = ***26,475,300.0 Litters*** of biogas can be generated each day from the two resources available.

3.4. Analysis of Energy generation capacity of the biogas produced.

The power generation capacity can be calculated by making use of the LHV (lower heating value) of the biogas .Biogas is composed of Methane (CH_4, Typically 60-70% by volume) and carbon dioxide (CO_2, 30-40% by volume) [4] . An average value of 65% CH_4 content and 35% CO_2 content is assumed.

Biogas density (at STP of 1.013 bar and 15 °C) =1.1 kg/m3, [18].
LHV of Biogas = 21 MJ/m3 or 19.1 MJ/kg [18] . This is approximately 5.84kWh/m^3. (Conversion factor 1MJ=0.27778KWh)

With an assumption of 87 % overall efficiency, 43% electrical and 44% thermal efficiency,(Value taken from Generators specification). For the calculation of the electrical energy generated the LHV can be taken as:-

$= 5.84kWh/m^3 * 0.43 = 2.51\ KWh/m^3$. (Electrical) -- (11)

$= 5.84kWh/m^3 * 0.44 = 2.57kWh/m^3$ (Thermal) --- (12)

From (equation 7and 8) we have the total amount of biogas generated from the two resources, by using these values the power generation capacity of the daily biogas production can be estimated.

1) *KSTP Raw sludge*

*E (kWh)= LHV (Electrical) * BV/day -- (13)*

*=**36,057.41kWh/day** -- (14)*

*Thermal energy (kWh) = LHV (Thermal) * BV/day -------------------------------- (15)*

=36,919.33kWh/day-- (16)

Power (kW_e) = Energy / working hour per day ------------------------------------ (17)

=36057.41kWh /8h

*=**4,507.17kW**-- (18)*

Or for continuous power for 24 hours, the average power consumption for a day.

*Power (kW_e) =**1,502.4kW**-- (19)*

2) *Waste water from industries wet room canteen.(future value)*

*E(kWh)= LHV (Electrical) * BV/day -- (20)*

*= **30,395.6kWh/day** --- (21)*

*Thermal energy (kWh) = LHV (Thermal) * BV/day --------------------------------- (22)*

= 31,122.2kWh/day. -- (23)

Power (kW_e) = Energy / working hour per day ------------------------------------- (24)

=30,395.6 kWh /8hr --- (25)

*=**3,799.45 kW**-- (26)*

Or for continuous power for 24 hours, the average power consumption for a day.

*Power (kW_e) =**1,266.48kW** --- (27)*

Therefore a total amount of **66.45MWh/day** of electrical energy can be generated from the two resources. There is also a potential of generating **68.04MWh/day** thermal energy by implementing the appropriate technology.

The power (kW) calculation is mainly dependent on the working hours of the industrial shades or the average power consumption of the day can be calculated in 24 hours basis. In order to serve the full load demand of the industrial shades from the waste to energy DG system the size and type of the generators should be determined. By making an assumption of the total working hour to be 8hrs, the total power that can be served by the DG system will be the sum of the power from the two resources which is **8.31MW**.

3.5. **Design of Anaerobic Digester Units.**

The first step on designing an anaerobic digester is to determine or estimate the biogas generation potential on the basis of the available resources and availability of site for construction of the anaerobic digesters. Sizing the plant (digester, gasholder, etc.) is the next step in the planning process.

Types of plants

There are various types of plants. Concerning the feed method, three different forms can be distinguished:

1. Batch plants
2. Continuous plants
3. Semi-batch plants

Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labor input. As a major disadvantage, their gas-output is not steady [10].

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant, and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode [10].

If straw and dung are to be digested together, a biogas plant can be operated on a ***semi batch*** basis. The slowly digested straw-type material is fed in about twice a year as a batch load. The dung is added and removed regularly.

Concerning the construction, two main types of simple biogas plants can be distinguished:

1. fixed-dome plants
2. floating-drum plants

But also other types of plants play a role, especially in past developments. In developing countries, the selection of appropriate design is determined largely by the prevailing designing the region. Typical design criteria are space, existing structures, cost minimization and substrate availability. The designs of biogas plants in industrialized countries reflect a different set of conditions [10].

Considering the type of resources available a fixed dome digester which is a continuous plant is designed for this research.

3.5.1. Fixed-dome plants

The costs of a fixed-dome biogas plant are relatively low. It is simple as no moving parts exist. There are also no rusting steel parts and hence a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space. While the underground digester is protected from low temperatures at night and during cold seasons, sunshine and warm seasons take longer to heat up the digester. No day/night fluctuations of temperature in the digester positively influence the bacteriological processes [10]. The construction of fixed dome plants is labor-intensive, thus creating local employment. Fixed-dome plants are not easy to build. They should only be built where construction can be supervised by experienced biogas technicians. Otherwise plants may not be gas-tight (porosity and cracks).

Function

A fixed-dome plant is comprises of a closed, dome-shaped, digester with an immovable, rigid gas-holder and a displacement pit, also named ’compensation tank’. The gas is stored in the upper part of the digester. When gas production commences, the slurry is displaced into the compensating tank. Gas pressure increases with the volume of gas stored, i.e. with the height difference between the two slurry levels. If there is little gas in the gasholder, the gas pressure is low.

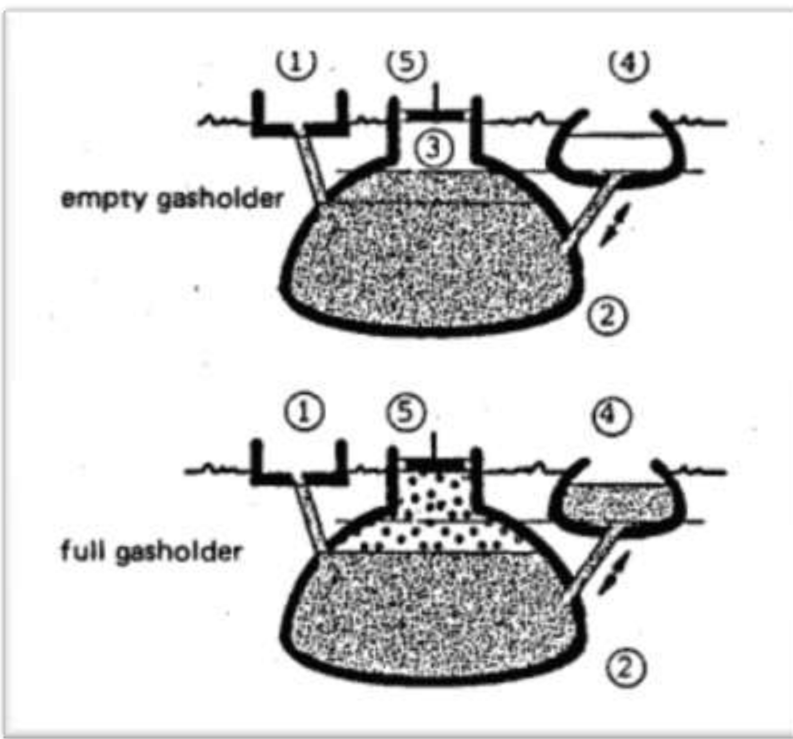


Figure 3-2: Basic function and components of a fixed-dome biogas plant, Source: [10].

1. Inlet tank with inlet pipe and sand trap.
2. Digester.
3. Gasholder.
4. Displacement pit
5. Gas pipe.

3.5.2. Sizing of the Fixed Dome Anaerobic Digester

The basic parameters for the sizing of an anaerobic digester are daily flow of substrate and biogas production potential of the substrate.

Design Parameters

1. Daily flow of substrate $1500m^3$
2. BV/day =14365.5 m^3/day resource from KSTP

Calculation

1. *Digester volume*

   Assume - substrate retention time SRT = 20days.

   Digester volume =SRT S/day*

$$= 300{,}000.0\ m^3 \quad\text{---}\quad (28)$$

2. *Digester sizing*

   Assume – there will be six cylindrical digesters with 30m diameter

   Active volume of each digester

$$=300000m^3 \div 6 = 5000.0m^3 \quad\text{--}\quad (29)$$

Surface area $\boldsymbol{A = \pi r^2}$ --- (30)

=706.5 m^2 -- (31)

*Active depth H= **volume ÷ surface area** -- (32)*

= 7.1m -- (33)

3. *Gas holder sizing*

Active volume of each gas holder

=14365.5 ÷6 =2394.2m^3-- (34)

The gas holder is a cut out of a hemisphere as shown below

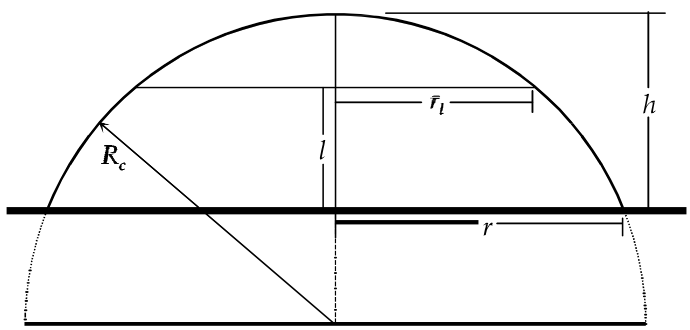


Figure 3-3 : Cut out hemisphere**.**

Volume = $\frac{\pi}{3}h^2(3Rc - h)$= = $\frac{\pi}{6}h(3r^2+h^2)$ --(35)

Volume=2394.2 m^3, r=15m .---(36)

Substituting values and calculating the value of h;

Height of the fixed dome calculated to be 6.4m.but constructing such a structure will be difficult therefore the height of the dome will be limited to 3m.and a separate gas collecting chamber is designed.

With a 3m height dome the volume of the gas holder will be

V=1074m^3--- (37)

4. *Gas storage tank sizing*

   A total volume of 14365.5 m^3 of biogas is generated from the resource available the six anaerobic digesters designed can accommodate 1074m^3 of biogas which is a total of 6444.0 m^3. The remaining gas of volume 7921.5m^3 should be collected in a separate Gas storage tank.

   A cylindrical Gas storage tank of 30m diameter is assumed.

   Surface area $A = \pi r^2$

   $= 706.5\ m^2$ -- *(38)*

   Active depth $H = volume \div surface\ area$

   $= 11.2m$-- *(39)*

5. *Inlet tank sizing*

   The inlet tank is assumed to be a simple manhole with an openable cover that will be used to retain the amount of sludge dumped from the tracks till it goes down to the digester , there will be 6 inlet tanks for each 6 reactors.

6. *Displacement pit*

   The displacement pit will be the same volume as the inlet tank with an over flow pipe. The effluent from the 6 reactors can be piped to the existing drying beds and sold out as fertilizers.

3.5.3. Biogas plant layout

Figure 3-4 below is a site plane for the KSTP taken form Addis Ababa Structural plan Land Use Around BOLE LEMI-Model (NORTHEC), and the proposed site layout for the biogas plant is shown In the same plane. The proposed site layout covers an approximate area of 20,000m^2 and consists of six anaerobic digesters, one gas collecting tank and Biogas fired Generators.

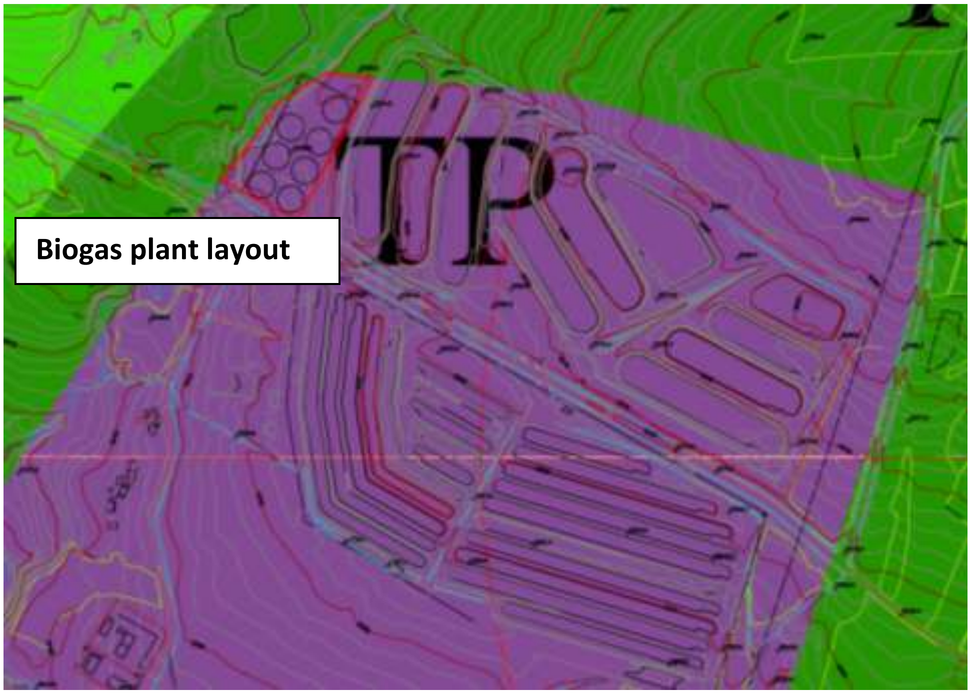


Figure 3-4: Proposed biogas plant layout site plane

Source: A.A Structural plan Land Use around BOLE LEMI-Model (Northec)

Figure 3-5 Shows the architectural three dimensional model of the biogas plant with the main components of the plant and piping arrangements are made part of the design. Other components which are not shown on the 3D model are Desulfurizer, to absorb H_2S, and Dehydrator, to reduce the water content of the biogas produced, these two components will be placed along the way of the gas piping.

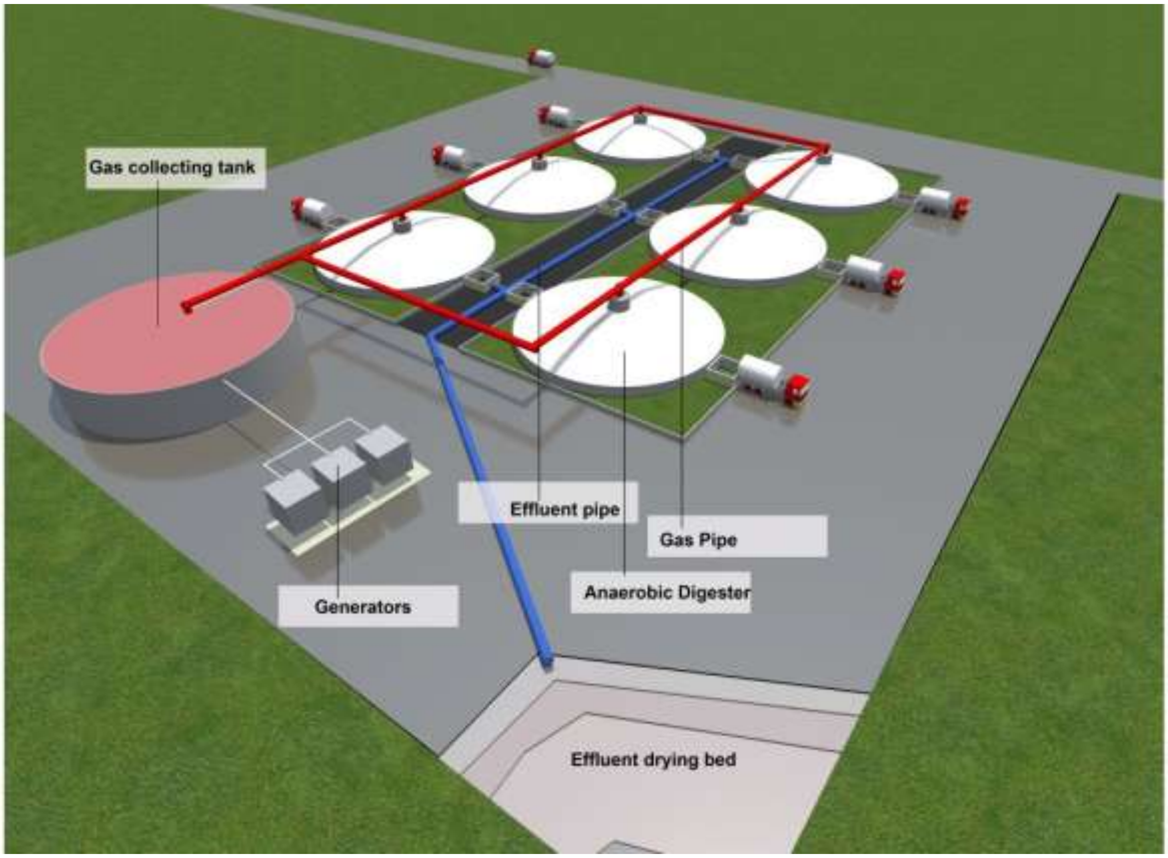


Figure 3-5 : Three dimensional (3D) model of the biogas plant.

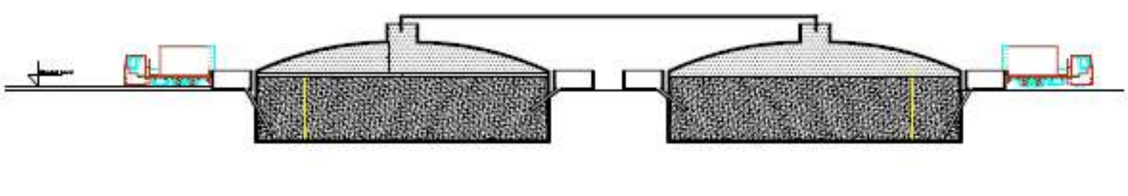


Figure 3-6: Sectional view of the biogas plant.

The sectional view shows the overall dimension of the digesters .The designed digester has a cylindrical shape with a diameter of 30m and depth of 7m below ground level and a dome shape for gas collection with a height of 3m above ground level. The detailed structural design and cost of construction is described in ANNEX II.

Table 3-3. Summary of Digester dimension for the biogas plant.

Specification	Value	Unit
Internal diameter of the digester	30000	Mm
Wall thickness	250	Mm
Dome wall thickness	200	Mm
Height of the digester	7000	Mm
Height of Dome	3000	Mm
Buried part of the digester	7000	Mm
Capacity	6074	m^3

From the capacity of the digester 6074 m^3 20 % is for biogas collection .The gas collected in the digester is piped through a copper or galvanizes steel pipes of appropriate size to the temporary gas storage chamber. From this chamber the biogas is again piped to the selected generators for power generation. The other option is to use liquefaction plants to liquefy the biogas generated and use it as a fuel for cars and tracks in the industrial zone.

3.6. **Selection of Generators**

After the gas is produced it pass through Desulfurizer and Dehydrator to meet the requirement of the gas engine of the generators and the purified gas is piped to the generators for power generation, As it is calculated in previous subsection, a total amount of ***36.057MWh/day*** of electrical energy can be generated from the KSTP resource. In order to generate this amount of energy the type and technology of generation should be selected carefully. For this research two option of generation is considered.

Option 1: Using Biogas fired Low voltage (230/400V) Standby power and Prime power Generators.

Option 2: Using Biogas fired Medium Voltage (15KV) Continuous Power Generators

Biogas fired generators are generators with an engine operated by biogases. The acceptable content of H_2S and moisture varies from engine to engine or from manufacturer to manufacturer therefore the Desulfurizer and Dehydrator has an important role in producing the required quality of biogas.

The size of the generator can be selected based on the energy generation capacity of the biogas generated each day from the 6 anaerobic digesters, which is 36.058MWh/day. These generators can be low voltage standby power generators, prime power generators or, medium voltage power generators to be connected to the grid.

3.6.1. Option 1: Using Biogas fired Standby power and Prime power Generators

These generators are generators with low voltage level 230/400V. The same generator can be used as standby or prime power generator the only difference is the time of generation of power. The standby power generator usually operate when there is a utility failure, if there is a reliable power supply from the grid this generators stay at standby. As it is discussed in previous chapter the amount of biogas generated each day should be consumed unless there is an adequate space for gas storage. In this particular research there is one gas collection chamber to collect the gas before piped to the generators, only for one day, therefore it is not recommended to use standby power generators for this research.

The other is the prime power generators; these are generators that can work continuously for a required amount of time .Therefore it is possible to use these generators for a continuous time until all of the biogas generated is consumed for the day. In order to determine the size of the generator an 8hr continuous power supply is considered and the power that can be generated in 8hr from the available biogas fuel is 4.5MW (Equation (18),Page 24).

Therefore a low voltage biogas fired generator that can supply the daily average power shall be selected for a stand-alone power generation that can be coupled with the EEU(Ethiopian Electric Utility) transformer with an automatic transfer switch and fuel level sensor. As the level of the biogas fuel reaches a certain set point the power automatically switched to the transformer.

The daily average power consumption of the industrial zone is taken from the data collected from the BLSS for three working days.

Table 3-4: BOLE LEMI 132KV substation incoming power in (MW)

Date of the year 2016			
	7-Nov	8-Nov	9-Nov
Hours	P (MW)	P (MW)	P (MW)
6.00	4.33	4.72	2.11
7.00	5.27	4.92	4.66
8.00	6.39	6.24	5.29
9.00	6.14	6.30	6.53
10.00	6.14	6.28	6.53
11.00	6.14	6.49	6.96
12.00	6.39	6.92	6.96
13.00	6.08	6.88	6.28
14.00	6.08	5.89	6.28
15.00	5.77	6.49	6.28
16.00	5.77	6.59	6.28
17.00	5.52	5.67	5.71
18.00	5.91	4.92	5.91
19.00	5.34	5.21	6.09
20.00	5.40	5.27	6.08

The load curve in Figure 3-7 shows the hourly average consumption for the three days

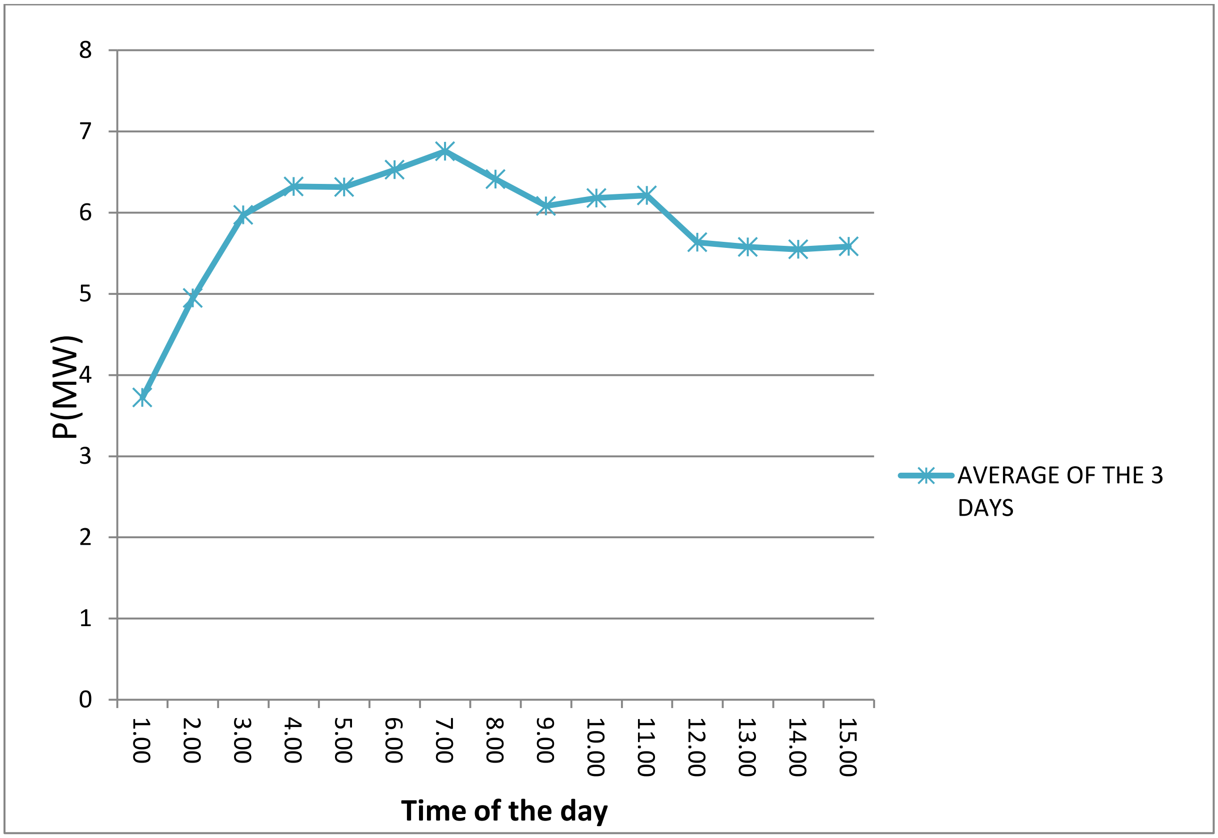


Figure 3-7: BOLE LEMI 132KV substation incoming loads in MW for 3 days average.

As it can be seen from the curve Figure 3- 7 the average peak load for the three day is around **6.76MW** and the peak load recorded in the three days is **6.96MW** and the average load is calculated and is equal to **5.85MW.** One of the three values can be used to determine the size of the DG system generators.

It is advisable to take the pick load which is 6.96MW so as to protect the generators from overloading. Therefore a generating station with a capacity of 8.00MW can be used.

The largest available biogas fired generator rating found in the global market is 2.00MW, 400V.Therefore it is preferred to use several small generators working in parallel to generate the desired amount of power. The main advantage of using small generators in parallel are;

- The generators can operate according to the load demand, when there is a small demand only one or two of the generators will be loaded and when there is a high demand all of them will be operational.
- When there is a small biogas fuel available or when there is a small generating capacity only one or two generators can operate while the rest are disconnected this makes the generators more efficient.
- Maintenance:- during maintenance generation will not be interrupted this increases reliability.
- Failure: - if one of the generators fails to operate the others will still be working this also makes the system reliable.

For this case four pieces of **2.0MW** generators are selected to serve the required power generation which makes a total of **8.0 MW** before de-rating.

"De-rating" is where the nominal rating of equipment is reduced, to compensate for adverse operating conditions. For most electrical equipment, power and current ratings are based on maximum component temperatures, i.e. amount of heat produced, and how fast that heat can be rejected to the atmosphere.

So any factor that increases temperature, or restricts cooling, tends to require a de-rating factor. Generally, generators need to be de-rated if the ambient temperature is higher than some nominal temperature. Equipment may also need to be de-rated for high altitudes. Air density decreases with altitude, which reduces the cooling capacity of air, as well as the de-electric strength of air.

De-rating Factor is therefore a factor which determines the capacity of the generator with respect to the altitude and temperature of the site of installation. The ratings of generators given by manufacturers are at some standard conditions. And the de-rating factor multiplier is different from manufacturer to manufactures and it is usually given in their specification sheets.

3.6.2. Option 2- Biogas fired Medium Voltage Continuous Power Generator

Medium voltage biogas fired generators are generators with a voltage level of 11KV, 15KV or more. These are usually used for power generation to be connected to the grid or for a stand-alone power generation for off-grid areas.

For this research these generators can be used as the waste to energy DG system to be connected to the grid. These generators are not easily available in the market most of the biogas generators are with a voltage level of 400V. The Medium voltage level generators are manufactured under request; the generator specifications found in the market so far are 11KV, **2.0MW** and **3.770MW**.

In this case the size of the generating station is determined by making use of 24 hour of generation. Within the 24 hour, the total power that can be generated from the biogas available is **1.5MW.** The size of the generator can be selected based on this value or a higher rating of generator, so that the generators can supply the base load of the industrial shads when power interrupted from the grid. There for the capacity of the generator is selected using the three days average load which is **5.85 MW**. In order to serve this load three pieces **2.0MW** generators are used.

From the available biogas fired generators in the market three generator specifications are evaluated according to the selection criteria’s set in this research to be used in both scenario. And the overall technical specifications of each generator are attached in ANNEX –III, IV and V.

Table 3-5 : Table of comparison for three biogas fired generators.

		ENGINE TYPE		
Description	**Unit**	**C2200N5C CUMMINS**	**CATCG170-20 CATERPILAR**	**TCG-2020 MWM**
Cont.Electrical power @1.0pf	KWe	2000	2000	2000
Thermal output	KW	2131	2021	
Thermal Efficiency	%	44.2	43.3	43.3
Electrical efficiency	%	43.0	42.9	42.9
Overall efficiency	%	87.2	86.2	86.2
Bore/stroke	Mm	180/200	170/195	170/195
Displacement,	L	91.6	88.5	88.5
Aspiration		Turbo charged		Turbo charged
Mean effective Pressure	bar	19.9	18.6	
Speed,	Rpm	1500	1500	1500
Piston Speed,	m/s	10	9.8	
Dimension (LxWxH)	M	6.07x2.16x2.79	6.2x1.71x2.19	6.2x1.71x2.19
Genset Weight	Kg	20477	17200	17900

		ENGINE TYPE		
Description	**Unit**	**C2200N5C CUMMINS**	**CATCG170-20 CATERPILAR**	**TCG-2020 MWM**
Lube oil Capacity,	L	550		
Minimum Methane Index		73	130 for biogas 70 -natural gas	80
NOx Emissions, @5% O2	mg/Nm^3	500	500	500
Voltage level	Kv	0.4	11	0.4
Step-up Transformer required for grid connection	Kv/kv	0.4/15	11/15	0.4/15
Minimum heating value (LHV)	kWh/Nm^3	9.3	5	5

Table 3-5 shows the various parameters for the three generators found in the market,

The important parameters are:-

- *Electrical and Thermal efficiency*; the overall efficiency for the C2200N5C is greater than all the three but the electrical efficiency is almost the same for all the generators.
- *Dimension*; All the dimensions are in acceptable range
- *Methane number & LHV*; the methane number or methane index and LHV are specifications of the fuel quality required by a specific engine. Methane Number, Lower Heating Value, and Sulfur Content criteria must be met to pass a given fuel for a specific engine. The biogas fuel used must meet the minimum quantity of methane number specified and the LHV. Though all the engines require the same amount of LHV the methane number differs, and the highest of the three is 130.

- *Voltage level.* In order to meet the required volt*age* level, 15KV, a step up transformer of 0.4/15kv and 11/15kv can be used after generation.
- NOx Emissions all of the emission are the same.
- Availability of spare parts and after sales service and price are also the most important factors of selecting the generators.

After evaluating all the parameters the **CATCG170-20 CATERPILAR** engine is selected to be the generating station for the DG system designed for grid and off-grid connection. It is mainly selected because of the availability of the engine supplier in the Ethiopian market.

In this study software known as Hybrid Optimization Model of Electric Renewable (HOMER) has been employed to decide which of the power generation option is economically advantageous.

HOMER, the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. This software would facilitate in many decisions about the configuration of the system; including the architecture of system, the sizes of the equipment's, and the cost of technology. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations [19].

To use HOMER, one should provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help one compare configurations and evaluate them on their economic and technical merits. In addition it is possible to export the tables and graphs for use in reports and presentations [19].

The system is modeled first as standalone and then with grid connection and the simulation result is shown in the figures bellow. The input parameters for the software are; annual average biomass resource, load data, cost of fuel, capital cost, O&M (Operation and maintenance) cost and other related relevant parameters.

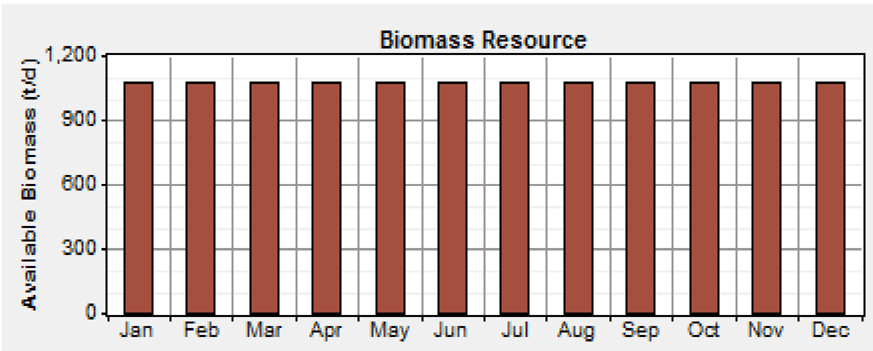


Figure 3-8 . *Biomass resource*

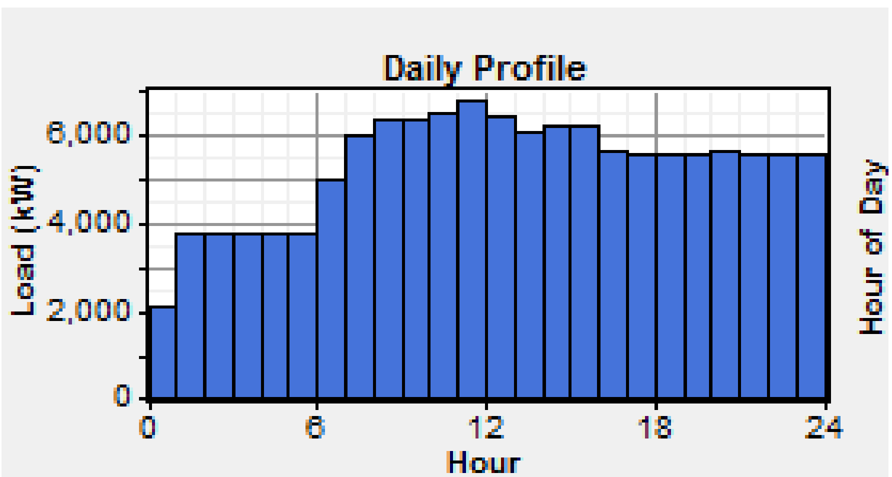


Figure 3-9 : *Daily load profile for 24 hours.*

The load profile collected from the BLSS is only for 15 hours, the rest is assumed to be the average of the collected data.

These two values are used for both method of connecting the DG system.

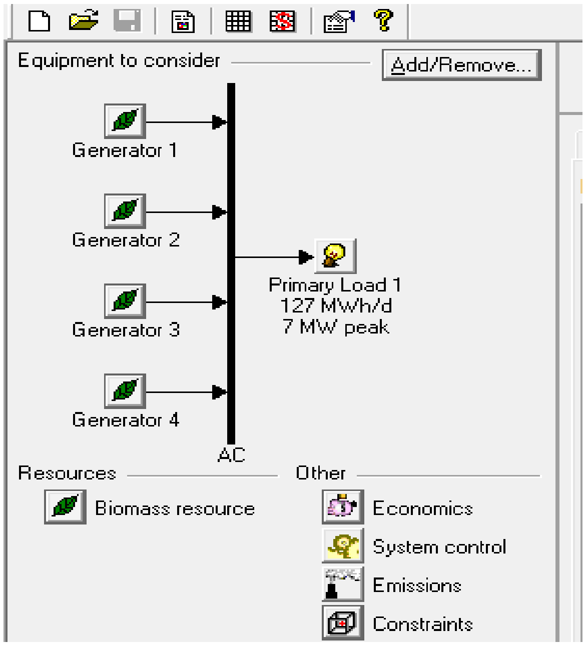


Figure 3-10: Equipment arrangement in the stand alone system.

The simulation result for the first option four generators serving the load as stand-alone system is shown in the figure below.

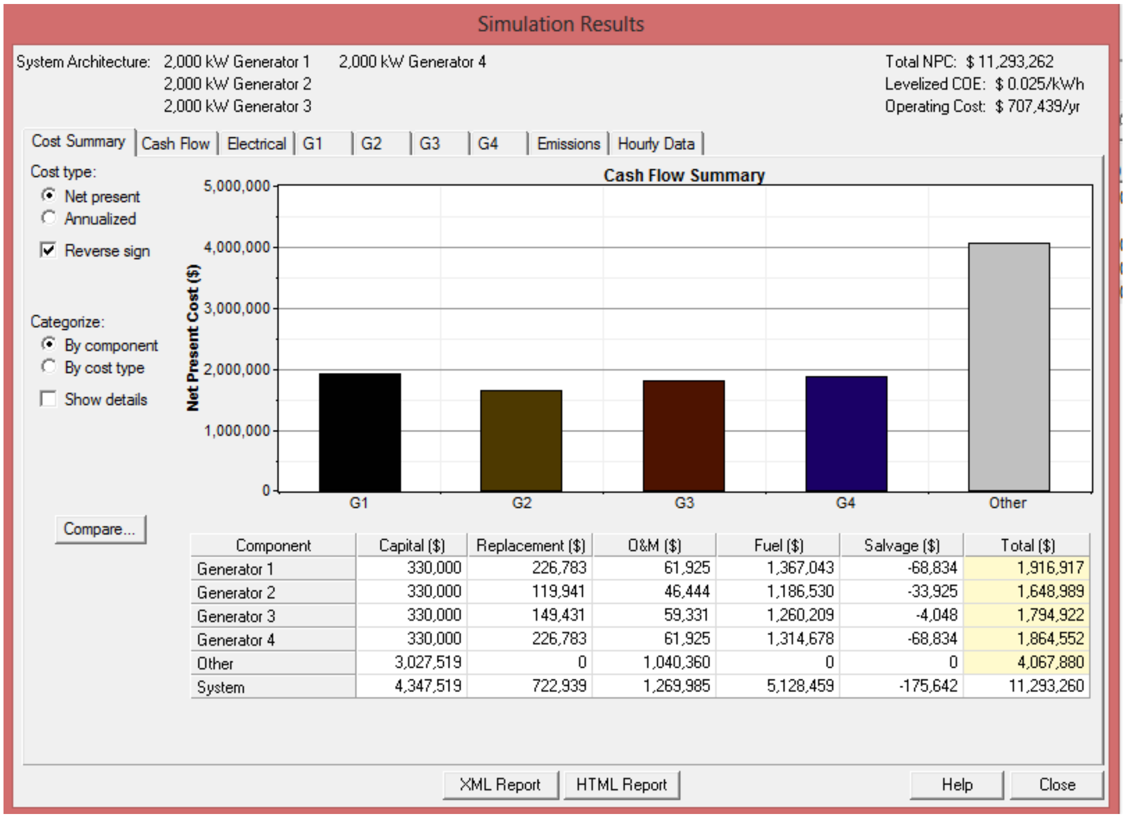
Sensitivity Results | Optimization Results

Double click on a system below for simulation results.

G1 (kW)	G2 (kW)	G3 (kW)	G4 (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biomass (t)	G1 (hrs)	G2 (hrs)	G3 (hrs)	G4 (hrs)
2000		2000	2000	$ 4,017,519	679,194	$ 10,685,949	0.024	1.00	0.17	101,5...	8,760		8,395	8,760
2000	2000	2000		$ 4,017,519	679,201	$ 10,686,013	0.024	1.00	0.17	101,5...	8,760	8,395	8,760	
2000	2000		2000	$ 4,017,519	679,201	$ 10,686,013	0.024	1.00	0.17	101,5...	8,760	8,395		8,760
	2000	2000	2000	$ 4,017,519	679,201	$ 10,686,013	0.024	1.00	0.17	101,5...		8,395	8,760	8,760
2000	2000	2000	2000	$ 4,347,519	707,439	$ 11,293,262	0.025	1.00	0.00	104,4...	8,760	6,570	8,393	8,760

Figure 3-11: Optimization result for stand-alone system.

From the optimization result the proposed case with four pieces of generators of capacity 2.00MW is simulated.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator 1	330,000	226,783	61,925	1,367,043	-68,834	1,916,917
Generator 2	330,000	119,941	46,444	1,186,530	-33,925	1,648,989
Generator 3	330,000	149,431	59,331	1,260,209	-4,048	1,794,922
Generator 4	330,000	226,783	61,925	1,314,678	-68,834	1,864,552
Other	3,027,519	0	1,040,360	0	0	4,067,880
System	4,347,519	722,939	1,269,985	5,128,459	-175,642	11,293,260

Figure 3-12: Simulation result for proposed case.

The simulation result shows that the system is feasible with the net present cost (NPC) of USD 11,293,262 and LCOE 0.025/kWh.

The second scenario calculated by the optimization software is the DG system connected to the grid.

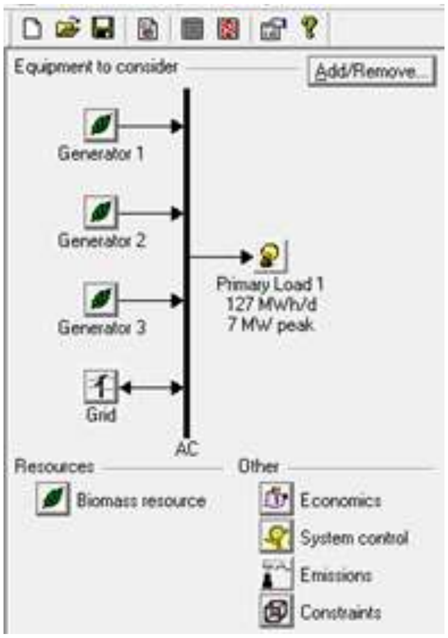
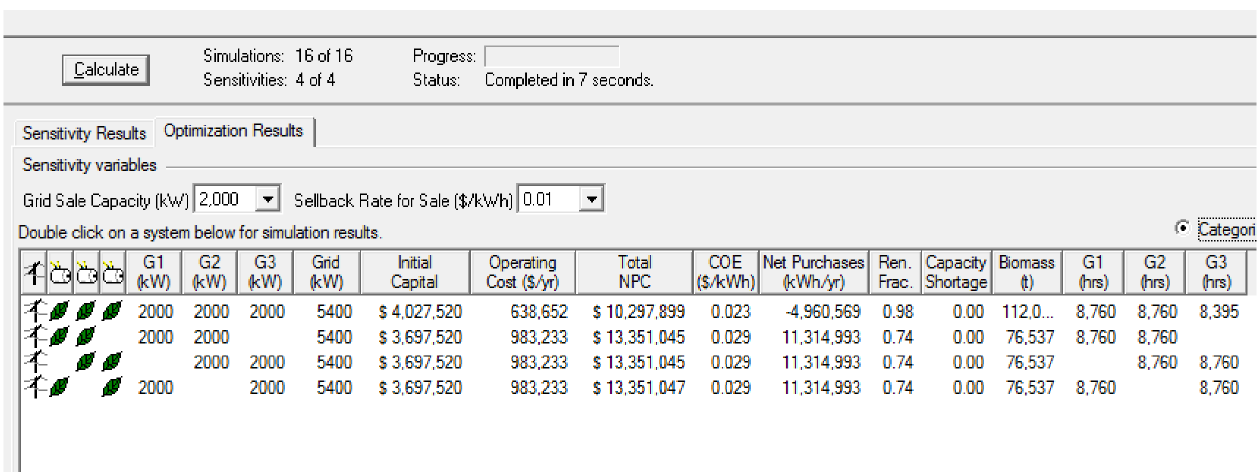


Figure 3-13: Equipment arrangement for grid connected system

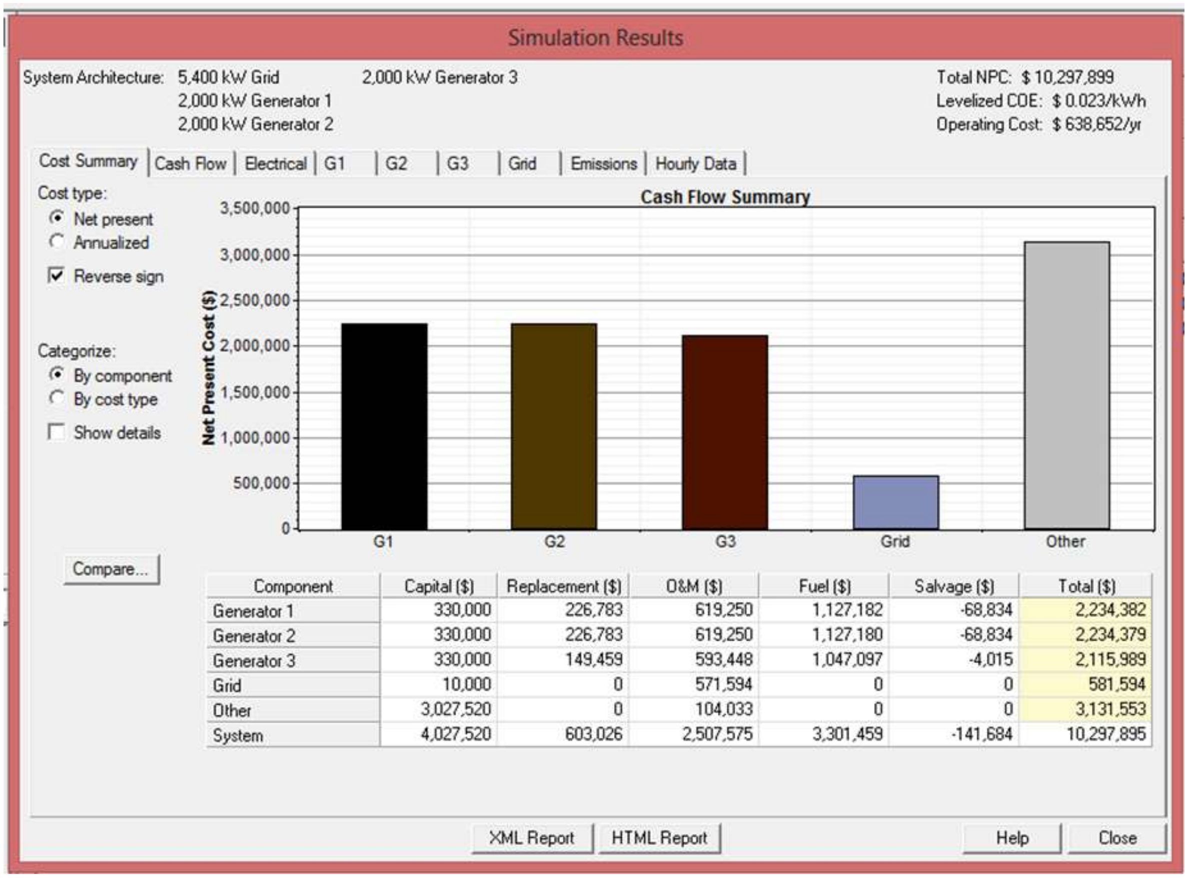
As it can be seen in the figure the proposed system with three pieces of 2.00MWgenerators are connected to the grid. The optimization result is shown in the figure below.



G1 (kW)	G2 (kW)	G3 (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Net Purchases (kWh/yr)	Ren. Frac.	Capacity Shortage	Biomass (t)	G1 (hrs)	G2 (hrs)	G3 (hrs)
2000	2000	2000	5400	$ 4,027,520	638,652	$ 10,297,899	0.023	-4,960,569	0.98	0.00	112,0...	8,760	8,760	8,395
2000	2000		5400	$ 3,697,520	983,233	$ 13,351,045	0.029	11,314,993	0.74	0.00	76,537	8,760	8,760	
	2000	2000	5400	$ 3,697,520	983,233	$ 13,351,045	0.029	11,314,993	0.74	0.00	76,537		8,760	8,760
2000		2000	5400	$ 3,697,520	983,233	$ 13,351,047	0.029	11,314,993	0.74	0.00	76,537	8,760		8,760

Figure 3-14: optimization result of system with grid connection.

From the four results the first optimization result which is three generators connected to the grid is simulated as shown in the figure



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator 1	330,000	226,783	619,250	1,127,182	-68,834	2,234,382
Generator 2	330,000	226,783	619,250	1,127,180	-68,834	2,234,379
Generator 3	330,000	149,459	593,448	1,047,097	-4,015	2,115,989
Grid	10,000	0	571,594	0	0	581,594
Other	3,027,520	0	104,033	0	0	3,131,553
System	4,027,520	603,026	2,507,575	3,301,459	-141,684	10,297,895

Figure 3-15: Simulation result for 3generators connected with the grid.

The simulation result shows that the system is feasible with the net present cost (NPC) of USD 10,297,899 and LCOE 0.023/kWh.

3.7. Connecting the Waste to Energy DG system with the Grid

According to the data collected from EEP the industrial shades are fed from a newly constructed substation named BOLE LEMI. The substation is connected by a 3.5 km long 132kV transmission line to the grid at a tap point of KALITI-1 to - KOTEBE substation transmission line. There is a three winding transformer 132/33/15kV with a capacity of 50MVA

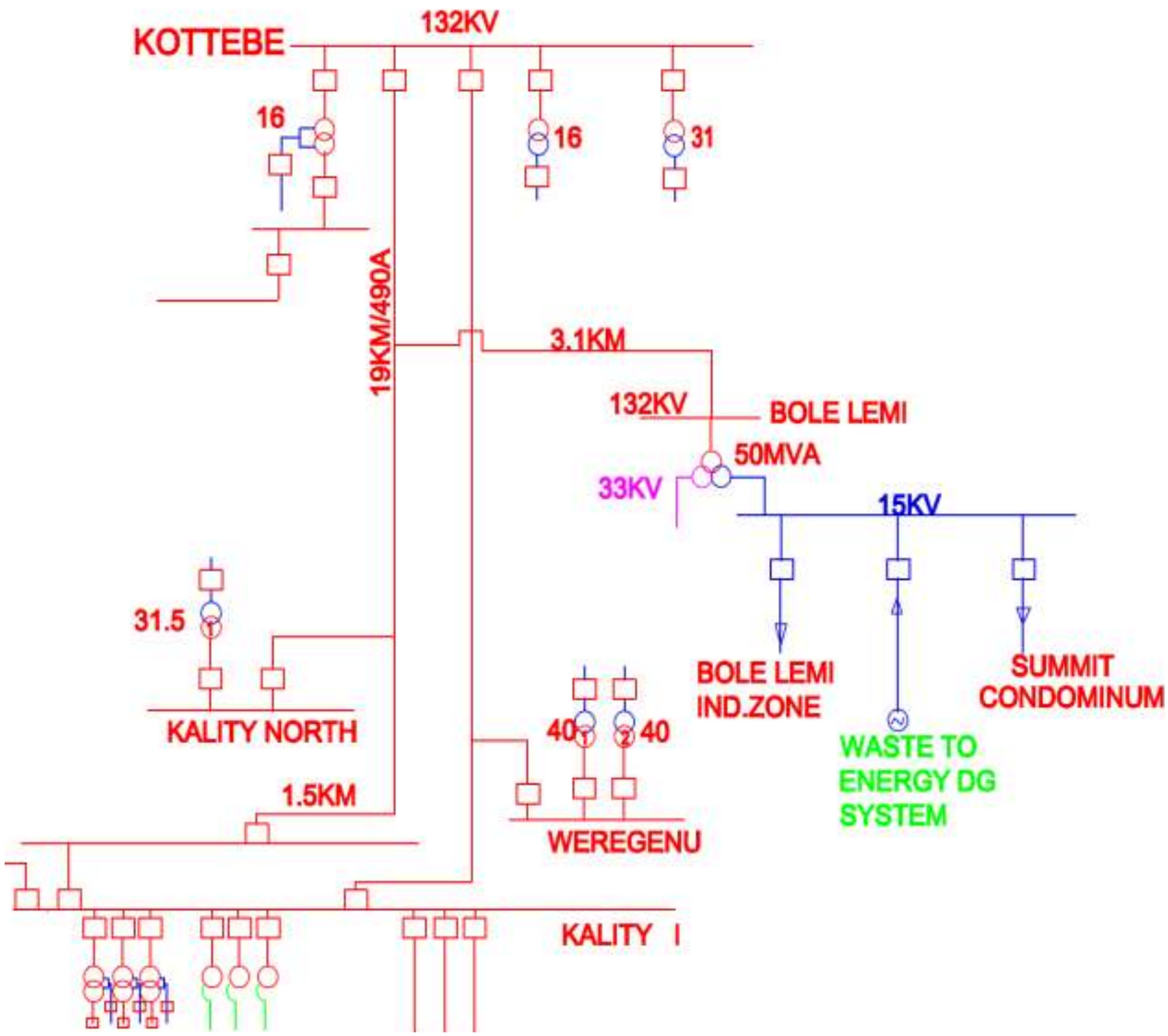


Figure 3-16. Transmission single line diagram for Bole Lemi and surrounding network. Source (EEP, Load Dispatch Center (LDC)).

As it can be seen from the above single line diagram this transmission line is simply tapped, (i.e. without a circuit breaker) and the KALITY I substation is usually overloaded. Whenever there is a fault in either of the two substations, or on the transmission line that links the two stations, the incoming line for Bole Lemi substation (BLSS) will also be affected, the power reliability at this substation is mainly dependent on the two substations and the transmission line where it is tapped.

Then the Waste–to Energy DG system can be directly connected to the 15kV side of the BLSS and this system can serve the load of the industrial zone at peak load time and it will supply power for the grid at off-peak load time.

The main advantage of the connecting the DG system are;

- There will be a load sharing for the KOTEBE-KALITY I substation; overloading decreases
- When there is a fault on the main grid and if the line opens the DG system will serve the load; power reliability and stability increases.
- The waste-to energy creates a clean environment; odder pollution decreased.
- The heat from the CHP (combined heat and power) generation can be used for anaerobic digester floor heating; increased efficiency of anaerobic digestion. This can also be used for hot water system supply for the factories.

The three things to be considered before making a grid connection are:

1. Synchronization
2. Feed in tariff policy (FIT)
3. Ownership of the DG system

3.7.1. Synchronization:

The generators from the DG system and the grid need to be synchronized. In order to synchronize a generator to the Grid, four conditions must be met [20].

- *Phase Sequence*: The phase sequence (or phase rotation) of the three phases of the generator must be the same as the phase sequence of the three phases of the electrical system (Grid). The only time that the phase sequence could be wrong is at initial installation or after maintenance.
- *Voltage Magnitude:* The magnitude of the sinusoidal voltage produced by the generator must be equal to the magnitude of the sinusoidal voltage of the grid. Before a generator is synchronized to the grid, there is no current flow, no armature reaction and therefore the internal voltage of the generator is the same as the terminal voltage of the generator. If the generator voltage is higher than the grid voltage, this means that the internal voltage of the generator is higher than the grid voltage. When it is connected to the grid the generator will be overexcited and it will put out MVAR. If the generator voltage is less than the grid voltage, this means that the internal voltage of the generator is lower than the grid voltage. When it is connected to the grid the generator will be under-excited and it will absorb MVAR.
- *Frequency:* The frequency of the sinusoidal voltage produced by the generator must be equal to the frequency of the sinusoidal voltage produced by the grid. If the generator speed is slower than the Grid, the Grid tries to bring it up to speed and if the generator is faster than the Grid, the Grid will try to slow it down in this process the stator and the rotor would be slipping pols and the generator might probably be damaged.
- *Phase Angle*: the phase angle between the voltage produced by the generator and the voltage produced by the grid must be zero. The phase angle (0 to 360°) can be readily observed by comparing the simultaneous occurrence of the peaks or zero crossings of the sinusoidal waveforms of the generator and the Grid. If the

generator breaker is closed when they match exactly, the connection will appear smooth and seamless.

The instrument, which will provide this information, is the Synchroscope. In AC electrical power systems, a Synchroscope is a device that indicates the degree to which two systems (generators or power networks) are synchronized with each other [21].

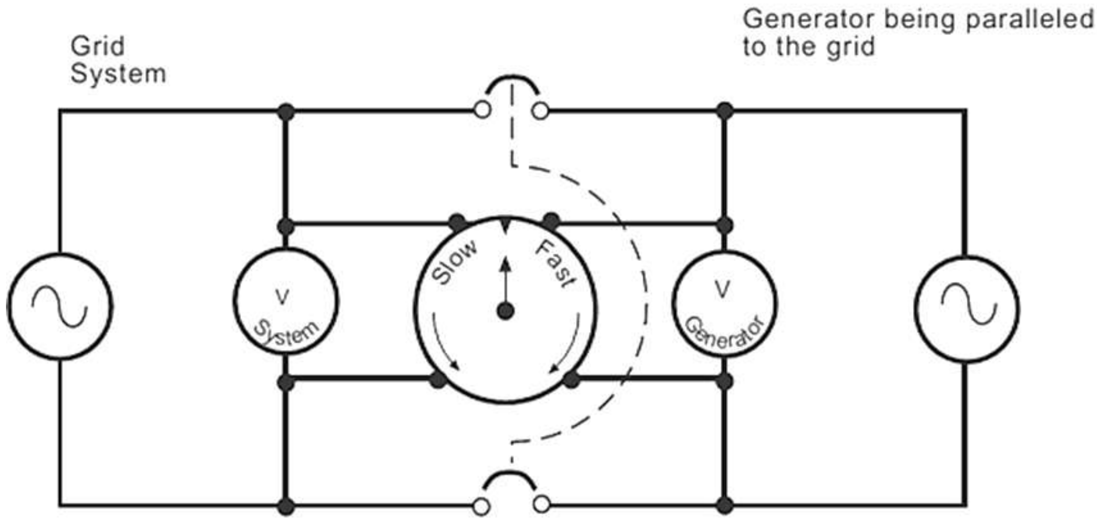


Figure 3-17 : Synchroscope checking Angle and Frequency.

Source: [20].

Figure 3-8 shows the connection of a synchroscope between the generator being synchronized and the Grid.

3.7.2. Feed in tariff policy (FIT)

The second thing to be considered during grid connection is the feed-in tariff policy of the country. FIT is payment made to households or businesses generating their own electricity through the use of methods that do not contribute to the depletion of natural resources, proportional to the amount of power generated.

The Government of Ethiopia decided to establish the necessary legal and regulatory frameworks through the presentation of Energy Proclamation No. 810/2013, which also provided for the establishment of the Ethiopian Energy Authority (EEA) [22].

“Expanding electricity generation from renewable sources of energy for domestic and regional Markets’’ is one of the Four pillars for the green economy strategic plan that Federal Democratic Republic of Ethiopia (FDRE) developed on *Ethiopia’s Climate Resilient Green Economy (2011)* that will ensure that Ethiopia achieves economic development goals in a sustainable way.

The Energy Proclamation has also empowered the regulatory Authority to perform its role, regarding regulation of both grid-connected and off-grid tariffs [22].

Additionally, Article 32 of the draft Energy Operation Regulation (dEOR) states that EEA may issue directives to be followed by all licensees for computation of expenses, costs, revenues, depreciation , working capital, return on capital etc., as may be appropriate, as well as other accompanying costs for the computation of the components of the revenue requirements.

A draft FIT proclamation has already been submitted by EEA to the Council of Ministers. The draft bill sought to establish Feed-In tariffs for Independent Power Producer (IPPs) producing electricity from different grid-connected RE sources with installed capacities below 10MW [22].

According to the FIT policy the power generated by the DG system will be eligible to be connected to the grid. Therefore the Grid connection can be realized following the rules and regulations of the Ethiopian FIT policy.

3.7.3. Ownership of the DG system

This green power generating station can be owned by three different entities. There will be a different scenario regarding the connection fees and FITs.

- EEP: If it is owned by EEP this power generated will be a support for the existing substation and a daily average power of 1.5MW will be supplied to the grid. In this scenario the investment cost will totally be for EEP and there will be no FIT considered.
- AASWA: The DG system can be a property of the AASWA. In this case the power generated can be directly sold to EEP. FIT will be considered based on the Renewable Energy (RE) utilized. The odor from the waste disposal will be removed. This is the other advantage for the AASWA.
- FMOI: the third entity that can own this DG system is FMOI. In this case the investment cost will be for the FMOI and the DG system will be connected to the grid and during utility failure base loads for the industries can be supplied from this system this will improve the power system reliability for the industries. And during off-peak load hours the system can support the grid.

In any of the three arrangements all the three entities and the people living in the surrounding will benefit from the system designed.

3.8. **Environmental Impact Analysis**

The sludge disposal facility at KOTEBE consists of 20 drying beds and 10 lagoons. The sludge lagoons are used in the rainy season to store sludge until the dry season. From the sludge lagoons the sludge can be pumped to the drying beds. The sludge in the drying bed is expected to evaporate through natural process to the environment and surge to the surface. This contributes for environmental pollution mainly bad odor to the surrounding, increased atmospheric concentration of methane, which is a power full greenhouse gas, and under ground water contamination due to pathogens from human faces this may have severe effect in public health.

Environmental Impact Assessments (EIA) have been carried out for Sludge Treatment Facility at KOTEBE and KALITY by previous researchers [2]. And the main environmental issues and proposed mitigation measures were summarized as :-

1. Health and Safety :-Training and awareness program for workers related to handling hazardous materials, together with the provision of adequate protective clothing and medical services
2. Bad Odors:- Creation of a buffer zone between residential areas and drying beds and lagoons.
3. Contamination of Water Resources Proper dried sludge disposal at sanitary landfill sites and disposal of seepage water
4. Non-aesthetic views Creation of a buffer zone between residential areas and sludge treatment facilities.

After the construction of the Green power Generating station using the waste –to- energy technology the aforementioned environmental issues will be mitigated as follows.

1. Health and Safety:-Training and awareness program for workers related to handling sludge disposals to the anaerobic digesters, together with the provision of adequate protective clothing and medical services.
2. Bad Odors:- There will be nothing to evaporate to the environment therefore the bad odor will be minimized.
3. Contamination of water resources:- the anaerobic digesters are designed with appropriate water proofing material and there will be no seepage water to the underground. Due to the anaerobic process all the harmful bacteria and pathogens will be eliminated and the digestate will be a pure quality bio fertilizer.
4. Non-aesthetic views:- The construction of the generation station will create a clean and esthetically attractive site views.

4. ECONOMIC ANALYSIS OF THE SYSTEM

In order to say a technology developed or a project designed is feasible or realizable it is mandatory to know and understand the value of the technology which is tried to be developed. The main interest of investors, or government, is the profit from the technologies that are developed. That's why it is necessary to perform an economic analysis for any project designed and technology developed.

There are so many different types of economic analysis methods which sometimes make different conclusions. Economic analysis method can be defined as a technique which helps investors to decide the best economic alternative including zero alternatives (doing nothing). Economic alternative means the alternative that makes bigger profits or advantages than the others. Therefore, the best economic alternative can be different according to the economic circumstance of projects [23].

Among the many methods for the economic analysis, those may be easy to understand, simple to use, applicable to projects or popular to others should be selected. The three popular economic analysis methods which are applicable for projects are Net present value method (NPV), Internal Rate of Return Method (IRR) and Payback period method (PB).

1. **NPV:** Present value means the result of transforming the future value into present value by use of given discount rate. Therefore NPV means the monetary gap between the present value of life cycle revenues of a project and that of costs. The decision to develop a particular deposit is based on the net present value (NPV). NPV must be positive for a project to be considered worthwhile [23].

2. **IRR:** Rate of return means the rate of interest that makes the present value of life cycle revenues equals that of costs. So, internal rate of return represents the rate of interest that makes net present value of a project 0. Therefore when the rate of return of a

project is bigger than the required marginal attractive rate return, the project is judged as being economic.

3. **PB:** Payback period means the time period when sum of the annual revenues gets over the amount of the initial investment. Thus when the payback period is shorter than the life cycle of the facility, the project is judged as being economic. PB is a good indicator of fast capital recovery.

The main objective of the economic analysis of the DG system is to demonstrate that the system is economically viable if it is designed and operated appropriately.

The construction and erection of the DG system includes the processes listed below.

1. Acquiring the required plot of land and appropriate site location.
2. Designing the system, Architectural, Structural, Sanitary, Mechanical And Electrical
3. Design permit and tendering of the project.
4. Site clearing and bulk excavations.
5. Construction of the anaerobic digesters and the erection of Generators.
6. Sanitary, Mechanical and electrical installations
7. Connecting the system to the grid.
8. Environmental impact analysis.

The analysis therefore is to determine the economic feasibility of implementing this project at BLIZ. It is expected that the result will guide prospective investors or Ethiopian Electric Power (EEP) before committing their resources.

4.1. Economic Investment Model

The following economic investment model has been used in the estimation of the various costs associated with implementing the DG system.

The total capital cost consists of the following:

1. Planning and project management costs; this includes the cost of design, design permit, Tendering and all other costs related to project management. It is usually 10% of the construction cost.
2. Engineering and construction costs; this is the cost of constructing the plant, installing mechanical and electrical equipment's.
3. System Installation and supervision costs; this includes system wiring, piping and related works and over all supervision of the project from starting of construction up to handover.
4. Mechanical equipment cost;
5. Electrical equipment cost;
6. Civil works and infrastructure cost. This cost is related to site civil works and other infrastructure costs for the power plant.

Table 4-1; Summery of total capital cost for the DG system

No	Description	Cost in (USD)
1	Planning and project management	170,632.63
2	Engineering and construction	1,706,316.32
3	System Installation and supervision	469,236.99
4	Mechanical equipment	178,019.20
5	Electrical equipment (switch gears and interconnection fee)	539,028.80
6	Generators & step up transformers	330,000.00
7	Civil works and infrastructure	281,542.20
	Total	**3,027,519.95**

Operation and Maintenance (O&M) Cost: The total O&M cost comprises both the fixed and variable operation and maintenance costs, over the life of the power plant. The maintenance cost covers the following components:

1 *Preventive or routine maintenance*; these are routine or planned maintenance activities which tend to minimize plant outages due to unexpected system malfunctions.

2 *Unscheduled maintenance*; these are unplanned maintenance activities due to forced system outages.

3 *Major overhauls and subsystem replacement;* this is a major maintenance activity or sub-system replacement activity which occurs once every 3 or 5 years.

In addition to the above maintenance costs, the following cost elements could be considered:

- Staff cost;
- Replacement parts and consumables (i.e. oil, lubricants etc.);
- Taxes;
- Land use payment;
- Insurance

In the absence of detailed O&M cost breakdown, the following industrial benchmarks O&M cost is used to perform the economic analysis of the DG system [22].

Table 4-2; Benchmark O&M cost.

No	RE Technology	O&M as a percentage of Capital Expenditure
1	**Biomass**	1.0% - 6.0%
	Wind:	
	On – shore	2.5% - 4.4%
	Off – shore	3.5% - 5.5 %
3	**Geothermal**	2.0% - 3.0%
4	**Solar :**	
	Solar Thermal	1.0% - 2.5%
	Solar PV	1.5% - 2.5%
5	**Hydro**	
	Large Hydro	2% - 2.5%
	Medium and Small	3% - 4%
	Hydro	

Sources: [22] (ATKINS ,2015)

As it can be seen from **Table 4-2** the O&M as a percentage of the capital expenditure is 1-6%. Therefore an average amount of 3.5% is taken, and the system O&M cost will be **105,963.00USD** which is **5,298.16 USD/yr.** for 20 years.

In order to perform the economic analysis of the system RETScreen clean energy project analysis software is used.

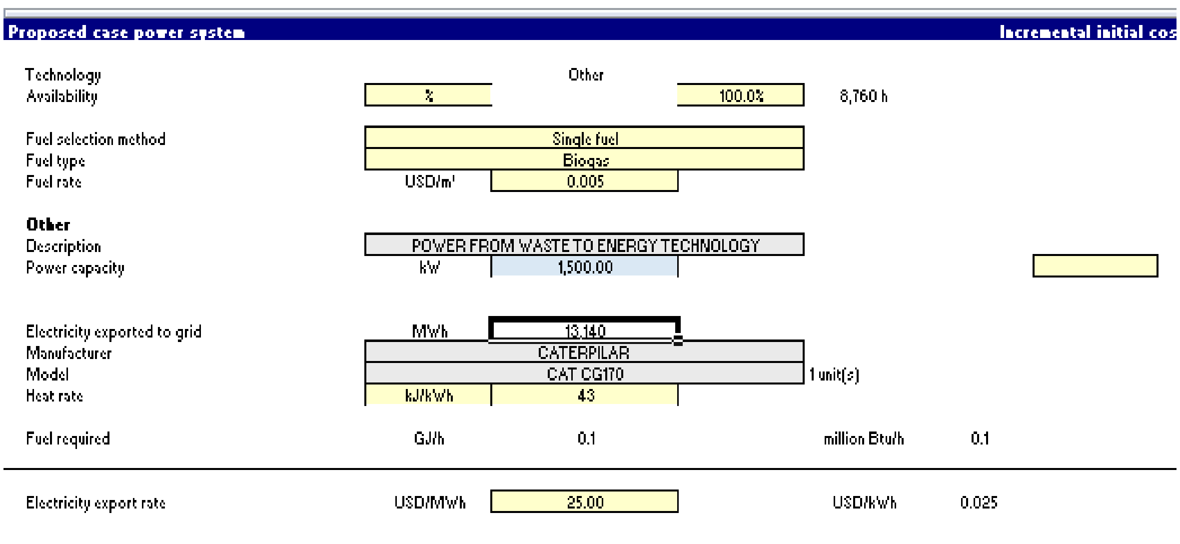
The RETScreen Software Suite is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The software, can be used to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient

Technologies (RETs). There are two separate programs, RETScreen 4 and RETScreen Plus, described below.

RETScreen 4; is an Excel-based clean energy project analysis software tool that helps decision makers quickly and inexpensively determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects.

RETScreen Plus; is a Windows-based energy management software tool that allows project owners to easily verify the ongoing energy performance of their facilities.

The simulation result of the dg system is shown in the three consecutive figures bellow.



Proposed case power system					Incremental initial cos
Technology		Other			
Availability	%		100.0%	8,760 h	
Fuel selection method		Single fuel			
Fuel type		Biogas			
Fuel rate	USD/m³	0.005			
Other					
Description		POWER FROM WASTE TO ENERGY TECHNOLOGY			
Power capacity	kW	1,500.00			
Electricity exported to grid	MWh	13,140			
Manufacturer		CATERPILAR			
Model		CAT CG170		1 unit(s)	
Heat rate	kJ/kWh	43			
Fuel required	GJ/h	0.1		million Btu/h	0.1
Electricity export rate	USD/MWh	25.00		USD/kWh	0.025

Figure 4-1:RETScreen simulation result

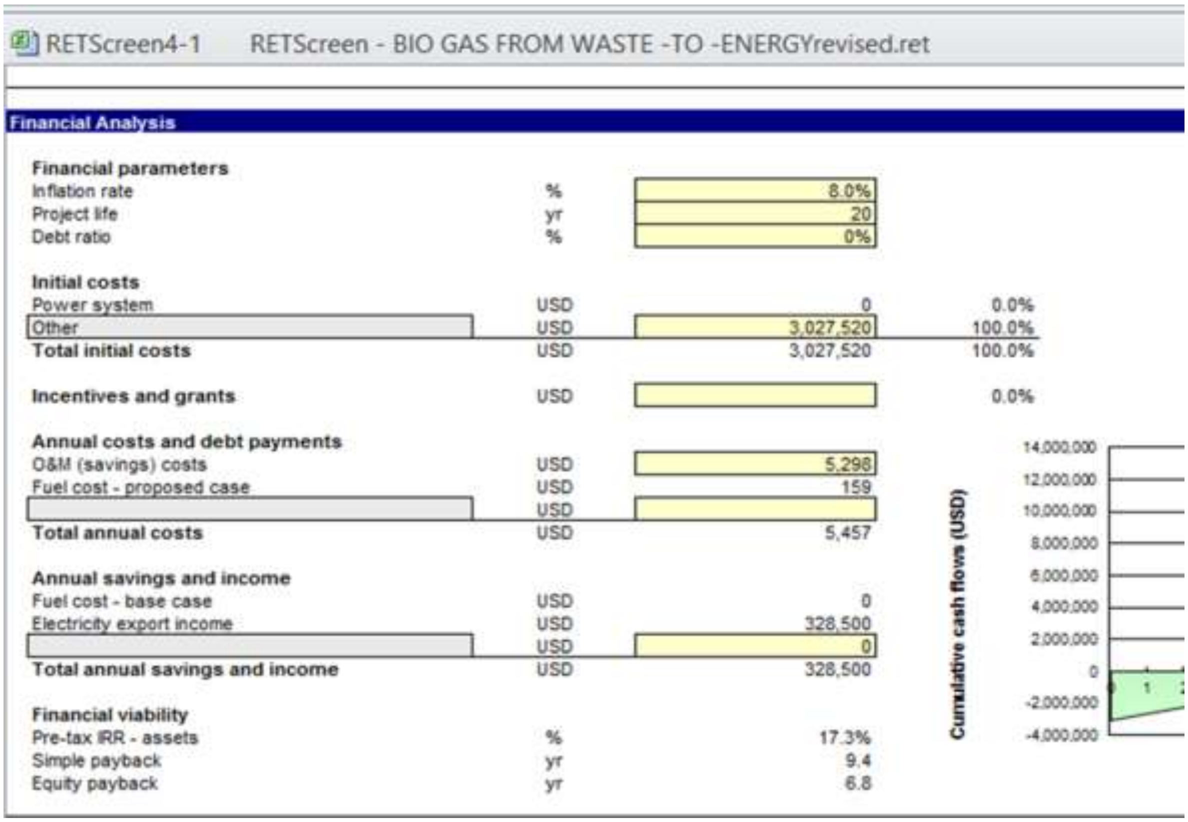


Figure 4-2 : RETScreen Financial Analysis

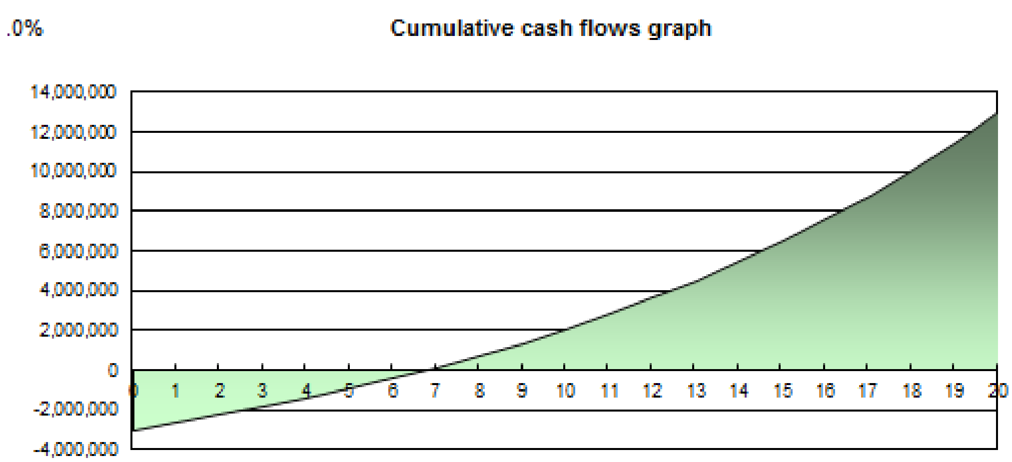


Figure 4-3: RETScreen cumulative cash flow graph.

The three pictures are the simulation result from the RETScreen for financial analysis and cumulative cash flow making use of the date feed for proposed case power system.

The result shows that the waste to energy DG system connected to the grid is economically feasible with IRR of 17.3%, Payback period of 9.4year. The cumulative cash flow graph shows a big incremental benefit after the 9.4 year.

5. RESULTS AND DISCUSSION

5.1. Generation of Green Power.

The two main objectives of the research are generation of green power and a clean environment for the BLIZ. It is discovered that there are two potential resources for the production of biogas, the KSTP resource and Waste water from industries wet room& canteen. A biogas volume of 26,475.3m^3/day can be generated from these two resources. And from this amount of biogas per day the total amount of electrical energy that can be generated is calculated to be 66.45MWh/day and there is also a potential of generating 68.04MWh/day thermal energy using the appropriate type of technology.

For further calculation and design of the DG system, only the KSTP resource is used throughout the research. The type and the number of Anaerobic Digesters are designed based on the value of this resource.

As it can be seen on Figure 3-5 Six Anaerobic Digesters, one temporary biogas collecting chamber and power generators are the main components of the DG system. After determining the number of the Anaerobic Digesters, two options of generator connections are studied

Option 1: Standby power and Prime power biogas fired generators; For this option two types of generator connections are further studied, Prime power and stand by power generators, Four pieces of 2.0MW low voltage 400V prime power generators to supply the total load as a standalone unit, until the biogas generated is totally consumed for the day, is used . The advantage of this scenario is the system serves the load as long as there is a biogas and the substation can serve other loads during these times. The main disadvantage is the utility failure may occur by the time the biogas is totally consumed; this does not minimize the problem of power reliability.

As it can be seen from the HOMER optimization software the optimization result for this particular case (**Figure 3-11**) there are 5 results and the one with four generators are simulated and the result shows that the system is considered feasible with a levelized cost of energy (LCOE) equals USD 0.025/kWh and (NPC) of USD 11,293,262 and zero capacity shortage.

Option 2: Connecting the DG system to the grid at the 15kV side of the BLSS using a high voltage biogas fired generators. According to the draft FIT policy of the country the DG system is eligible to be connected to the grid. The system is designed to serve at least the base load of the industrial shades which is the daily average value 5.85 MW, in order to serve this load three pieces 2.0MW generators are used .

As it can be seen from the result of the optimization software **Figure 3-14** there are 4 various results. The first in the list, three generators connected with the grid, is taken as proposed case and further simulated.

The simulation result shows the system is feasible with net present cost (NPC) of USD 10,297,899 and LCOE 0.023/kWh.

When we compare the two option of connecting the DG system the NPC and the LCOE for the DG system connected to the grid is less than the first option of connecting the DG system as a standby power supply.

Therefore the waste to energy system with three pieces of 2.0MW generators connected to the grid is taken as the DG system.

Further economic analysis is done using standard software called RETScreen to determine the IRR and the PB of the DG system. As it can be seen in the result **Figure 4-2 Figure 4-1:RETScreen simulation result** pretax IRR is 17.3% which is positive .The simple payback period is 9.4 years and the cumulative cash flow graph in **Figure 4-3** shows a big incremental benefit after the 9.4 year .Therefore it can be concluded that the waste to energy DG system connected to the grid is economically feasible.

5.2. **Clean Environment**

The second objective of this research is creation of clean environment for BLIZ. Waste-to-energy technologies create an important opportunity for countries like Ethiopia where the lack of waste treatment is a threat to the public health and environment. As a legal citizen all person has environmental rights as stated in deferent parts of the constitution of the FDRE.

The constitution is the supreme law of the land and it was adopted by Ethiopia in 1995 and provides guiding principles for environmental protection and management thereof in Ethiopia. The concept of sustainable development and environmental rights are stated in Article 43, 44 and 92 of the constitution. Article 43 defines the people's right to improved living standards and sustainable development. Similarly, Article 44 states that all persons in Ethiopia have the right to clean and healthy environment. Article 92 states that the design and implementation of projects in Ethiopia shall not damage or destroy the environment and that government and citizens have the duty to protect the environment.

A number of proclamations and supporting regulations contain provisions for the protection and management of the environment and put into effect the principles of the constitution and the environmental policy. Since the industrial zone is the home of big investors, the odor pollution might have a significant effect on the workers and for the buyers of the industries.

By implementing this waste to energy technology in the BOLE LEMI area, the people’s right towards the clean environment will be secured.

The clean environment is actually created in the process of trapping the biogas in the anaerobic digester, the waste disposed in the lagoons will be contained in the anaerobic digester and the odder for the surrounding will decrease automatically, because of the production of the biogas, the clean environment is therefore the byproduct of the power generation. The other useful byproduct of this power generation is high quality bio-fertilizer, which can be sold to farmers.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The manufacturing plants in the BLIZ demand a great deal of sufficient and reliable energy to function properly and meet their target. In order to fulfill this demand EEP has constructed a mobile substation with a capacity of 50MVA power using 3.1km transmission line taped from KOTTEBE - KALITY I 132KV transmission line dedicated only for the industrial shades. But these substations are usually over loaded and whenever there is a fault in one of the substations the BLSS will also be affected .On the other hand there is a waste disposal pond in the near proximity 0.3km from the industrial zones which pollutes the surrounding environment .It is concluded that the research can solve these two big issues for the BLIZ by using the waste to energy technology to generate green power and a clean environment for the surrounding. A DG system is designed using biogas from the waste as a renewable resource and it is discovered that a total 66.45MWh/day of electrical energy can be generated. There is also a potential of 68.04MWh/day thermal energy generation from the two resources described in the research if an appropriate technology is implemented. Using only the resource from the KSTP a total of 36.057MWh/day electrical energy can be generated. From the two methods of connecting the DG system described, the DG system connected to the Grid is found to be economically feasible with LCOE $0.023/kWh. It also increases the reliability of the power system for the BLSS and as a result of the biogas generation the odor pollution will be reduced and the environment for the surrounding will be clean.

6.2. Recommendation

From the two biomass resources studded in this research the KSTP resource is the available resource and the resource from the industrial wet rooms is a potential resource and a future value is considered to estimate the biogas generating potential. The available KSTP resource is taken to further calculate the power production of the DG system and to construct the anaerobic digesters. Therefore it is recommended to further study the resource potential from the wet room and restaurant wastes as well as waste water treatment plant of each industry and to make site arrangement for constructing additional anaerobic digesters to transform the waste to useful energy.

The other recommendation is to use CHP plant to utilize the thermal energy generated each day and increase the efficiency of the anaerobic digesters. Finally a further study is required about the connection of the DG system to the Grid and a detailed environmental impact analysis should also be carried out.

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APPENDIX I. AAWSA Kality And Kotebe Yearly Average (2008) Raw Sludge or night soil quality

Addis Ababa Water and Sewerage Authority
Kalitti and Kotebe wastewater treatment Plants
Yearly Average (2008) Raw sludge or Night soil Quality
(fecal sludge)

S.N	Parameters	Unit	Value
1	Raw sludge (night soil) volume	m^3/day	1246
2	Dried sludge cake volume	m^3/day	90
3	Temperature	^0C	20
4	PH	-	7.8
5	Biochemical oxygen demand, 5 days	mg/l	4800
6	Chemical oxygen demand	mg/l	37800
7	Total solids	mg/l	31500
8	Total dissolved solids	mg/l	6480
9	Volatile solids	mg/l	18600
10	Settle able solids	ml/l	120
11	Ammonia as NH_3	mg/l	2460
12	Phosphate as PO_4	mg/l	2865

N.B. Raw sludge (night soil) samples are collected from the mixture of pit-latrines and septic tanks waste

Analysed by ------------------------
Lab tech & chemist

Approved by ----------------------
Chemist

APPENDIX II . Cost of construction of the reactors

The cost of construction of the AD reactors is realized in two subsections, civil work and sewerage and biogas piping, a rough cost estimate is taken for each work.

Civil work

The civil work is the work for the AD structures, starting from excavation and site clearing a simple structural design and

Thickness

Bottom Slab= 500mm

Wall =250mm

Doom=200mm

Reinforcement

Bottom slab=Ø16 C/C 200 in both directions (top and bottom)

Wall = Ø14 C/C 200 in both directions (vertical)

= Ø10C/C 200 in both directions (horizontal)

Doom = Ø14 C/C 200 in both directions ((top and bottom)

Doom area = 1.3*Bottom slab area

$=1.3*\pi*15^2 = 918m^2$

Excavation

Depth of Excavation = 6m

Volume of excavation = base area * Depth

Base area = πr^2 (r=16m including working space)

$= \pi* 16^2=803.84m^2$

Volume= 803.84*6 = 4,823.04m^3

Price rate for excavation = 200birr/m^3 including cart away

Total price= 200*4,823.04=964,608 birr

Concrete

Bottom slab = area * thickness

Area=$\pi*15^2$ =706.5m^2 Thickness = 0.5 m

Volume= 706.5*0.5=353.25m^3

Wall=$2\pi rht$

r = 15m, h=7m,t=0.25 m

Volume = $2*\pi*15*7*0.25=165m^3$

Doom = Area of doom * Thickness

= 918*0.2=183.6m^3

Total concrete volume = 353.25+165+183.6=702m^3

Price rate for concrete=3000birr/m^3

Total price= 702*3000=2,106,000birr

Form work

Bottom slab= $2\pi rt$ t=0.5m r= 15m

$= 2\pi*15*0.5$

$=47.1m^2$

Wall= $(2\pi rh)*2$ r= 15m h= 7m , form work is considered in two faces.

$= 2 \pi *15*7*2$

= 1319m^2

Doom = Doom area= 918m^2

Total area = 47.1+1319+918= 2284.1m^2
Price rate for form work= 300birr/ m^2
Total price =2284.1*300
= **685,230birr**

Reinforcement

Bottom slab
Average length of bars=0.6D D=30m
=0.6*30=18m
Number in a single direction=30/0.2+1 = 151
Total Number=151*4 =604
Total length=604*18=10,872m

Wall

Length = 7.5m
Perimeter=2πr=2π *15=94.2m
Number of vertical bars=94.2/0.2=471
Total length= 471*7.5=3532.5m
Total length in two faces=3532.5*2=7065m
Number of horizontal bars=7.5/2=38m
Total length = 38m*94.2= 3580m
Total length in two faces= 3580m*2= 7160m

Doom

Average length of bars = 0.6D
Average D= 2*$\sqrt{(A/\pi)}$ = 2*$\sqrt{(918/\pi)}$= 34.2m
Average length = 0.6m*34.2 =20.5m
Number in a single direction = 34.2/0.2 +1 = 172
Total Number =172*4 = 688
Total length = 688*20.5 = 14,104m

Table 1-1 Summary of bars per type

	Diameter of Bar	Total length in Meter
Bottom slab	16	10,872
Wall	14	7065
	10	7160
Doom	14	14,104

Table 1-2 Summary of bars

Diameter of Bar	Mass(Kg/m)	Length (m)	Total Mass in kg.
16	1.548	10,872	16,826.6
14	1.185	21,169	25,085.3
10	0.604	7160	4324.6

Total mass= 46,236.5 kg
Including 10% wastage
Total Mass= 1.1*46,236.5=50,860.15kg

Price rate for reinforcement = 40birr/kg (market survey)
Total price= 50,860.15*40=2,034,406birr
Total Price= 964,608+2,106,000+685,230+2,034,406
= 5,790,244 birr ----price for one AD Reactor.
For the KSTP resource the structures designed are six AD reactors and one biogas storage tank. Assuming all the seven structures are the same the total price for the construction of the AD reactors will be.
=7 * 5,790,244
= 40,531,708 birr.

Cost of biogas sanitary and piping works
The cost of biogas sanitary and piping works includes, water proofing of the digester walls ,sewage drainage piping and biogas pipes from the digesters to the gas storage tank and from the tank to the generators, and all other materials used to make the system complete .

Table 0-1 Summery of cost of biogas sanitary and piping work

Item	Description	Unit	Quantity	Unit price	Amount
1	***WATER PROOFING WORK***				
	Apply high head tolerant MAX SEAL FLEX or Equivalent **Water Proofing** for floor and wall areas of the Digester as per the manufacturer's instructions and recommendations. The cost shall include cleaning of all dirt, trace of grease, oil and loose particles. The work shall be done on sub contractual bases with the supplier of the material which will give material & construction guarantee to the client.	m^2	4550	420	1,911,000.00
2	***SEWAGE PIPES***				
	Supply & Install Waste water drainage HDPE (PN-6) pipes complete with connecting pieces, fittings, anchors, fixing or hanging elements with all other necessary accessories. The pipes shall be provided with a minimum slope as shown in the drawing. The joints shall be made tight and installation shall make possible the best condition for cleaning & maintenance. Unit price shall include all necessary civil works there to. (Installation shall also follow manufacturers' instruction .) Diam.250m	ml	80	690	55,200.00

3	***GAS PIPES***				
	Supply & Install biogas Copper pipes of appropriate size complete with connecting pieces, fittings, anchors, fixing or hanging elements with all other necessary accessories. The pipes shall be provided with a minimum slope as shown in the drawing. The joints shall be made tight and installation shall make possible the best condition for cleaning & maintenance. Unit price shall include all necessary civil works there to. (Installation shall also follow manufacturers' instruction.) .Diameter 250mm	ml	200	800	160,000.00
	SUMMARY	Birr			**2,126,200.00**

APPENDIX iii. Cummins QSV91G Biogas Generator Technical Specification

Model: C2200 N5C
Frequency: 50 Hz
Fuel Type: Natural Gas MI 73 +
Emissions Performance NOx: 500 mg/Nm^3 (1.0 g/hp-h)
LT Water Inlet Temperature: 40°C (104°F)
HT Water Outlet Temp: 92°C (198°F)

Generator set data sheet
2000 kW continuous

Our energy working for you.™

Power Generation

Measured Sound Performance Data Sheet:	N/A
Prototype Test Summary Data:	N/A
Remote Radiator Cooling Outline:	N/A

Fuel Consumption (ISO3046/1)	See Note	100% of Rated Load	90% of Rated Load	75% of Rated Load	50% of Rated Load
Fuel Consumption (LHV) ISO3046/1, kW (MMBTU/hr)	2,4,6,7	5117 (17.48)	4658 (15.91)	3943 (13.47)	2866 (9.79)
Mechanical Efficiency ISO3046/1, percent	2,4,7	44.2%	43.7%	43.0%	39.5%
Electrical Efficiency ISO3046/1, percent	2,4,6,7	43.0%	42.5%	41.8%	38.4%

Engine	
Engine Manufacturer	Cummins
Engine Model	QSV91G
Configuration	V18
Displacement, L (cu.in)	91.6 (5591)
Aspiration	Turbocharged (1)
BMEP, bar (psi)	19.9 (265)
Bore, mm (in)	180 (7.09)
Stroke, mm (in)	200 (7.87)
Rated Speed, rpm	1500
Piston Speed, m/s (ft/min)	10 (1968)
Compression Ratio	13.0:1
Lube Oil Capacity, L (qt)	550 (581)
Overspeed Limit, rpm	1800
Regenerative Power, kW	N/A
Full Load Lubricating oil consumption, g/kWe-hr (g/hp-hr)	0.4 (0.3)

Fuel	
Gas supply pressure to engine inlet, bar (psi)[7]	0.2 (2.9)
Minimum Methane Index	73

Starting System(s)	
Electric starter voltage, volts	24
Minimum battery capacity @ 40 deg.C (104 deg.F), AH	780
Air Starter Pressure, barg (psig)	10.0 (145)
Air Starter Flow Nm^3/s (scfm)	0.37 (780)

Genset Dimensions (see note 1)	
Genset Length, m (ft)	6.07 (19.9)
Genset Width, m (ft)	2.16 (7.1)
Genset Height, m (ft)	2.79 (9.1)
Genset Weight (wet), kg (lbs)	20477 (45,144)

	See Notes	100% of Rated Load	90% of Rated Load	75% of Rated Load	50% of Rated Load
Energy Data					
Continuous Generator Electrical Output kWe @ 1.0 pf	6,10	2200	1980	1650	1100
Heat Dissipated in Lube Oil Cooler, kW (MMBTU/h)	3,5	270 (0.92)	236 (0.80)	204 (0.70)	186 (0.64)
Heat Dissipated in Block, kW (MMBTU/h)	3,5	525 (1.79)	479 (1.63)	447 (1.52)	334 (1.14)
Total Heat Rejected in LT Circuit, kW (MMBTU/h)	3,5	229 (0.78)	196 (0.67)	170 (0.58)	127 (0.43)
Total Heat Rejected in HT Circuit, kW (MMBTU/h)	3,5	1107 (3.78)	977 (3.33)	861 (2.94)	565 (1.93)
Unburnt, kW (MMBTU/h)	3,13	103 (0.35)	101 (0.34)	89 (0.30)	72 (0.25)
Heat Radiated to Ambient, kW (MMBTU/h)	13	329 (1.12)	297 (1.02)	249 (0.85)	180 (0.61)
Available Exhaust heat to 105C, kW (MMBTU/h)	3,5	1267 (4.32)	1187 (4.05)	1021 (3.48)	859 (2.93)
Intake Air Flow					
Intake Air Flow Mass, kg/s (lb/hr)	3,4	3.21 (25441)	2.95 (23332)	2.44 (19353)	1.82 (14415)
Intake Air Flow Volume, m3/s @ 0°C (scfm)	3,4	2.48 (5547)	2.28 (5087)	1.89 (4220)	1.41 (3143)
Maximum Air Cleaner Restriction, mmHG (in H_2O)		18.39 (9.8)	18.39 (9.8)	18.39 (9.8)	18
Exhaust Air Flow					
Exhaust Gas Flow Mass, kg/s (lb/hr)	3,4	3.33 (26361)	3.05 (24172)	2.53 (20054)	1.89 (14935)
Exhaust Gas Flow Volume, m3/s (cfm)	3,4	6.82 (14450)	6.32 (13391)	5.34 (11307)	4.23 (8957)
Exhaust Temperature After Turbine, °C (°F)	2,6	451 (844)	459 (858)	472 (881)	519 (966)
Max Exhaust System Back Pressure, mmHG (in H_2O)	6,14	36.77 (19.7)			
Min Exhaust System Back Pressure, mmHG (in H_2O)	6,14	18.38 (9.8)			
HT Cooling Circuit					
HT Circuit Engine Coolant Volume, l (gal)		498 (132)	498 (132)	498 (132)	498 (132)
HT Coolant Flow @ Max Ext Restriction, m^3/h (gal/min)		70 (308)	70 (308)	70 (308)	70 (308)
Maximum HT Engine Coolant Inlet Temp, °C (°F)	8	75 (167)	75 (167)	75 (167)	75 (167)
HT Coolant Outlet Temp, °C (°F)	8	92 (198)	92 (198)	92 (198)	92 (198)
Max Pressure Drop in External HT Circuit, bar (psig)		1.5 (22)	1.5 (22)	1.5 (22)	1.5 (22)
HT Circuit Maximum Pressure, bar (psig)		6.0 (87)	6.0 (87)	6.0 (87)	6.0 (87)
Minimum Static Head, bar (psig)		0.5 (7)	0.5 (7)	0.5 (7)	0.5 (7)
LT Cooling Circuit					
LT Circuit Engine Coolant Volume, l (gal)		59 (16)	59 (16)	59 (16)	59 (16)
LT Coolant Flow @ Max Ext Restriction, m^3/h (gal/min)		50 (220)	50 (220)	50 (220)	50 (220)
Maximum LT Engine Coolant Inlet Temp, °C (°F)	9	40 (104)	40 (104)	40 (104)	40 (104)
LT Coolant Outlet Temp, øC (°F) Reference Only	9	42.9 (109)	42.6 (109)	42.3 (108)	41.5 (107)
Max Pressure Drop in External LT Circuit, bar (psig)		1.5 (22)	1.5 (22)	1.5 (22)	1.5 (22)
LT Circuit Maximum Pressure, bar (psig)		6.0 (87)	6.0 (87)	6.0 (87)	6.0 (87)
Minimum Static Head, bar (psig)		0.5 (7)	0.5 (7)	0.5 (7)	0.5 (7)
Emissions					
NO_x Emissions wet, ppm	15	168	169	171	177
NO_x Emissions, mg/Nm^3 @5% O_2 (g/hp-h)	15	500 (1.0)	500 (1.0)	500 (1.0)	500 (1.0)
THC Emissions wet, ppm	13	1263	1341	1435	1557
THC Emissions, mg/Nm^3 @5% O_2 (g/hp-h)	13	1367	1440	1525	1599
CH_4 Emissions wet, ppm	13	1036	1100	1176	1277
CH_4 Emissions, mg/Nm^3 @5% O_2 (g/hp-h)	13	1140 2.25	1201 2.42	1272 2.62	1334 3.16
NMHC Emissions wet, ppm	13	227	241	258	280
NMHC Emissions, mg/Nm^3 @5% O_2 (g/hp-h)	13	246	259	275	288
CO Emissions (dry), ppm	3	642	648	648	663
CO Emissions, mg/Nm^3 @5% O_2 (g/hp-h)	3	1092 (2.16)	1093 (2.20)	1081 (2.22)	1063 (2.52)
O2 Emissions (dry), percent	3	9.2	9.1	9.0	8.5

Genset De-rating

Altitude and Temperature Derate Multiplication Factor

Barometer		Altitude						Table A *							
In Hg	mbar	Feet	Meters					Derate Multiplier with Grid Parallel Operation							
20.7	701	9843	3000												
21.4	723	9022	2750												
22.1	747	8202	2500	0.75	0.75	0.75	0.75								
22.8	771	7382	2250	0.80	0.80	0.80	0.80	0.75							
23.5	795	6562	2000	0.85	0.85	0.85	0.85	0.80	0.75						
24.3	820	5741	1750	0.90	0.90	0.90	0.90	0.85	0.80	0.75					
25.0	846	4921	1500	0.95	0.95	0.95	0.95	0.90	0.85	0.80	0.75				
25.8	872	4101	1250	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.80				
26.6	899	3281	1000	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.85	0.75			
27.4	926	2461	750	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.90	0.80			
28.3	954	1640	500	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.75		
29.1	983	820	250	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.80	0.75	
30.0	1012	0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	0.85	0.80	
			°C	0	5	10	15	20	25	30	35	40	45	50	55
			°F	32	41	50	59	68	77	86	95	104	113	122	131
			Air Filter Inlet Temperature												

* Based on SAE standard ambient pressure vs. altitude. Assumes LT return temperature is 10C above air filter inlet.

Altitude & Temperature Derate

1. Determine derate multiplier vs. temperature and altitude in Table A or B depending upon your operating condition.

2. Assumes the LT return temperature is 10 deg C above the air filter inlet with a maximum LT temperature of 40 deg C.

3. If the LT temperature exceeds 40 deg C, consult factory for recommendations.

4. Altitude is based upon SAE standard ambient pressure vs. altitude. For low barometric conditions add 150m (500 ft) to site altitude.

Heat Rejection Factor (altitude and ambient) for HT and LT Circuits

Barometer		Altitude		Table C								
In Hg	mbar	Feet	Meters	Multiplier for HT & LT Heat Rejection vs Alt & Temp.								
20.7	701	9843	3000	1.11	1.13	1.14	1.15	1.17	1.18	1.19	1.20	1.22
21.4	723	9022	2750	1.10	1.12	1.13	1.14	1.15	1.17	1.18	1.19	1.21
22.1	747	8202	2500	1.09	1.10	1.12	1.13	1.14	1.16	1.17	1.18	1.20
22.8	771	7382	2250	1.08	1.09	1.11	1.12	1.13	1.14	1.16	1.17	1.18
23.5	795	6562	2000	1.07	1.08	1.09	1.11	1.12	1.13	1.15	1.16	1.17
24.3	820	5741	1750	1.06	1.07	1.08	1.10	1.11	1.12	1.14	1.15	1.16
25.0	846	4921	1500	1.05	1.06	1.07	1.09	1.10	1.11	1.12	1.14	1.15
25.8	872	4101	1250	1.04	1.05	1.06	1.07	1.09	1.10	1.11	1.13	1.14
26.6	899	3281	1000	1.02	1.04	1.05	1.06	1.08	1.09	1.10	1.12	1.13
27.4	926	2461	750	1.01	1.03	1.04	1.05	1.07	1.08	1.09	1.10	1.12
28.3	954	1640	500	1.00	1.02	1.03	1.04	1.05	1.07	1.08	1.09	1.11
29.1	983	820	250	0.99	1.00	1.02	1.03	1.04	1.06	1.07	1.08	1.10
29.5	995	492	150	0.99	1.00	1.01	1.03	1.04	1.05	1.06	1.08	1.09
30.0	1012	0	0	0.98	0.99	1.01	1.02	1.03	1.05	1.06	1.07	1.08
			°C	20	25	30	35	40	45	50	55	60
			°F	68	77	86	95	104	113	122	131	140
			Air Filter Inlet Temperature									

LT & HT Circuit Heat Rejection Calculation

1. Determine derate multiplier vs. temperature derate per above.

2. Using the multiplier from #1 above as the percent load factor determine the Heat rejection from the previous page.

3. From Table C find the HT and LT circuit multiplier.

4. Multiply the result of step 2 by the result of step 3 to obtain the heat rejection at your altitude and temperature.

Methane Number Capability

Load (Percent of Rated)			
100%	90%	75%	50%
73	66	55	40

Alternator Data

Voltage Range	Connection Configuration	Temp Rise Degrees C	Duty[11] Cycle	Single Phase Factor	Maximum Surge kVA[12]	Alternator Data Sheet	Feature Code
400	Wye, 3 Phase	105	C	N/A	7354	517	
415	Wye, 3 Phase	105	C	N/A	7354	517	
3300	Wye, 3 Phase	105	C	N/A	7040	520	
6000	Wye, 3 Phase	105	C	N/A	6900	523	
6300	Wye, 3 Phase	105	C	N/A	6932	523	
6600	Wye, 3 Phase	105	C	N/A	6932	523	
10000	Wye, 3 Phase	105	C	N/A	6627	523	
11000	Wye, 3 Phase	105	C	N/A	6784	523	
380	Wye, 3 Phase	125	C	N/A	7354	517	
400	Wye, 3 Phase	125	C	N/A	7354	517	
415	Wye, 3 Phase	125	C	N/A	7354	517	
440	Wye, 3 Phase	125	C	N/A	7354	517	
3300	Wye, 3 Phase	125	C	N/A	7040	520	
6000	Wye, 3 Phase	125	C	N/A	6900	523	
10000	Wye, 3 Phase	125	C	N/A	6627	523	
10500	Wye, 3 Phase	125	C	N/A	6784	523	
11000	Wye, 3 Phase	125	C	N/A	6784	523	

Continuous Rating Definition

Applicable for supplying power continuously to a constant load up to the full output rating for unlimited hours. No sustained overload capability is available for this rating. Consult authorized distributor for rating. (Equivalent to Continuous Power in accordance with ISO8528, ISO3046, AS2789, DIN6271, and BS5514). This rating is not applicable to all generator set models.

Notes

1) Weights and set dimesions represent a generator set with its standard features only. See outline drawing for other configurations.
2) At ISO3046 reference conditions, altitude 1013 mbar (30in Hg), air inlet temperature 25 °C (77°F)
3) Production variation/tolerance ± 10%.
4) According to ISO 3046/I with fuel consumption tolerance of +5% -0%.
5) Production variation/tolerance ±5%.
6) At electrical output of 1.0 Power Factor.
7) Tested using pipeline natural gas with LHV of 33.44mJ/Nm3 (905BTU/ft3)
8) Outlet temperature controlled by thermostat. Inlet temperature for reference only.
9) Inlet temperature controlled by thermostat, outlet temperature for reference only.
10) With engine driven coolant pump.
11) Standby (S), Prime (P), Continuous (C)
12) Maximum rated starting kVA that results in minimum of 90% of rated sustained voltage during starting.
13) Tolerance +/- 15%
14) Exhaust system back pressure is a rated load and will decrease at lower loads.
15) Tolerance +/- 20%

APPENDIX IV. CAT CG170 Bio Gas Generator Technical Specifications

CAT® CG170

SMARTER ENERGY SOLUTIONS

COMMERCIAL AND INDUSTRIAL FACILITIES

Facilities such as manufacturing plants, resorts, shopping centers, office or residential buildings, universities, data centers and hospitals reduce operating costs and carbon footprint simultaneously.

ELECTRIC UTILITIES

Caterpillar has led innovation to deliver stationary and containerized gas power plants to electric utilities and district energy facilities around the world for both continuous grid support and peak electricity demand.

MINES

Mining operators increase mine safety and reduce carbon emissions with coal gas, while many other mining operations are realizing the benefits of onsite gas power generation to support greenfield site development.

AGRICULTURE AND FOOD / BEVERAGE PROCESSING

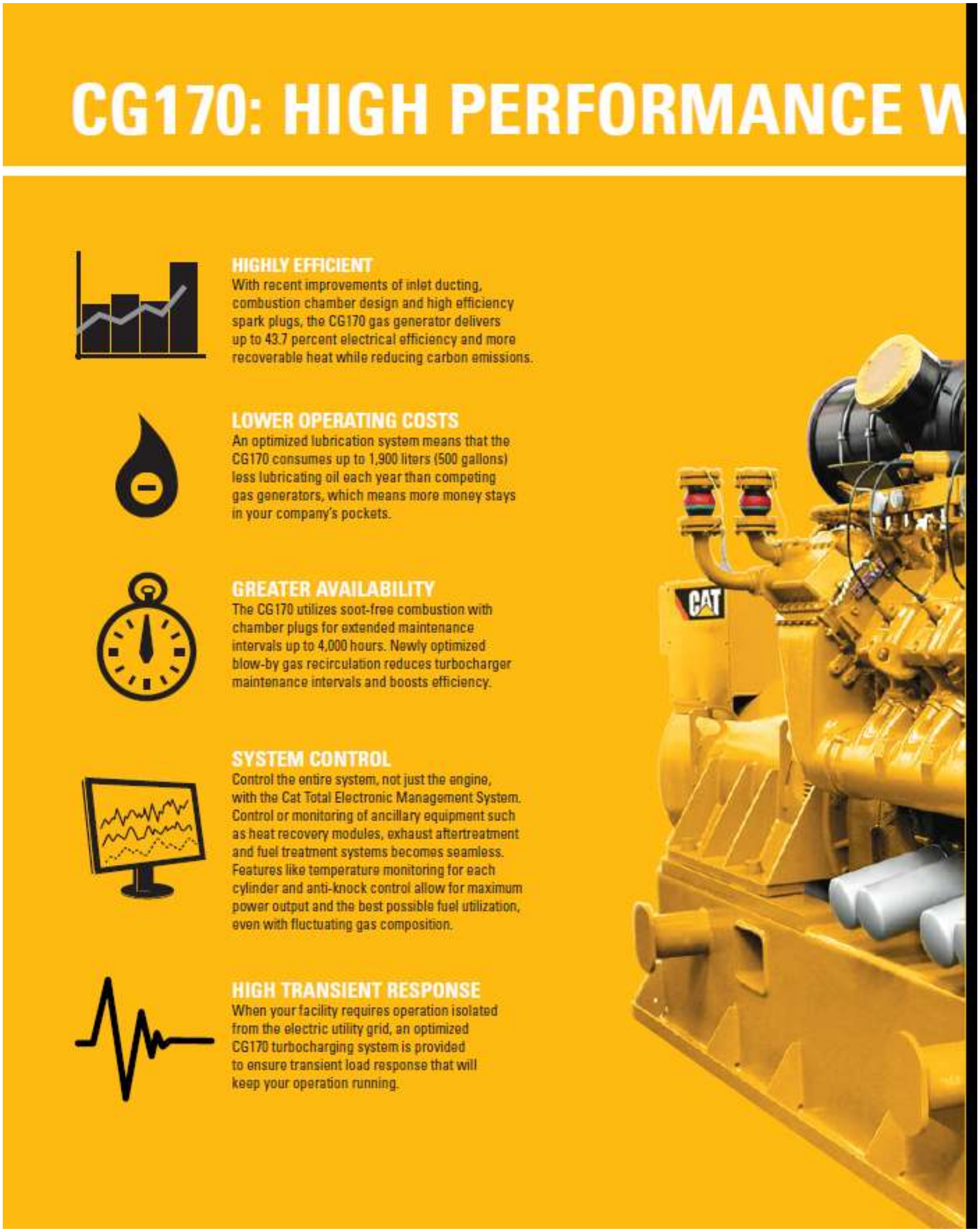
Biogas, a useful byproduct of the anaerobic digestion of organic waste, is created by food processors, ethanol and biodiesel manufacturers, and farms around the world as a renewable fuel resource for Cat® powered electricity generation.

LANDFILLS AND WASTEWATER TREATMENT PLANTS

Landfill and sewage gases are is generated by communities around the world as part of sanitary process infrastructure. Instead of destroying or flaring the methane gas produced, communities make beneficial use of this fuel as part of a sustainable energy program.

GREENHOUSES

In greenhouses, Cat gas generator sets simultaneously deliver electricity for lighting or sale to the local grid, hot water for facility heating, and carbon dioxide as an organic fertilizer for increased crop production.


CG170: HIGH PERFORMANCE W
HIGHLY EFFICIENT
With recent improvements of inlet ducting, combustion chamber design and high efficiency spark plugs, the CG170 gas generator delivers up to 43.7 percent electrical efficiency and more recoverable heat while reducing carbon emissions.
LOWER OPERATING COSTS
An optimized lubrication system means that the CG170 consumes up to 1,900 liters (500 gallons) less lubricating oil each year than competing gas generators, which means more money stays in your company's pockets.
GREATER AVAILABILITY
The CG170 utilizes soot-free combustion with chamber plugs for extended maintenance intervals up to 4,000 hours. Newly optimized blow-by gas recirculation reduces turbocharger maintenance intervals and boosts efficiency.
SYSTEM CONTROL
Control the entire system, not just the engine, with the Cat Total Electronic Management System. Control or monitoring of ancillary equipment such as heat recovery modules, exhaust aftertreatment and fuel treatment systems becomes seamless. Features like temperature monitoring for each cylinder and anti-knock control allow for maximum power output and the best possible fuel utilization, even with fluctuating gas composition.
HIGH TRANSIENT RESPONSE
When your facility requires operation isolated from the electric utility grid, an optimized CG170 turbocharging system is provided to ensure transient load response that will keep your operation running.
CAT

50 Hz PRODUCT PERFORMANCE

ENGINE TYPE	UNITS	CG170-12		CG170-16		CG170-20	
Bore/stroke	mm in	170/195	6.7/7.7	170/195	6.7/7.7	170/195	6.7/7.7
Displacement	l in³	53.1	3,240	70.8	4,320	88.5	5,401
Speed	rpm	1500		1500		1500	
Mean piston speed	m/s ft/s	9.8	32	9.8	32	9.8	32
Length [1]	mm in	4,640	183	5,360	211	6,200	244
Width [1]	mm in	1,810	71	1,810	71	1,710	67
Height [1]	mm in	2,210	87	2,210	87	2,190	86
Dry weight genset	kg lb	10,600	23,373	12,600	27,783	17,200	37,926

NATURAL GAS

ENGINE TYPE	UNITS	CG170-12		CG170-16		CG170-20	
Electrical power [2]	kW_e	1,200		1,560		2,000	
Mean effective pressure	bar psi	18.6	270	18.1	274	18.6	270
Thermal output (+/-8 %) [3]	kW Btu/m	1,189	67,677	1,576	89,705	1,977	112,530
Electrical efficiency [2]	%	43.7		43.3		43.7	
Thermal efficiency [3]	%	43.3		43.8		43.2	
Total efficiency	%	87.0		87.1		86.9	

$NO_x \leq 500$ mg/Nm³, 1 g/bhp-h

BIOGAS

ENGINE TYPE	UNITS	CG170-12		CG170-16		CG170-20	
Electrical power [2]	kW_e	1,200		1,560		2,000	
Mean effective pressure	bar psi	18.6	270	18.1	263	18.6	270
Thermal output (+/-8%) [3]	kW Btu/m	1,249	71,093	1,641	93,405	2,021	115,035
Electrical efficiency [2]	%	42.1		41.8		42.9	
Thermal efficiency [3]	%	43.8		44.0		43.3	
Total efficiency	%	85.9		85.8		86.2	

$NO_x \leq 500$ mg/Nm³, 1 g/bhp-h

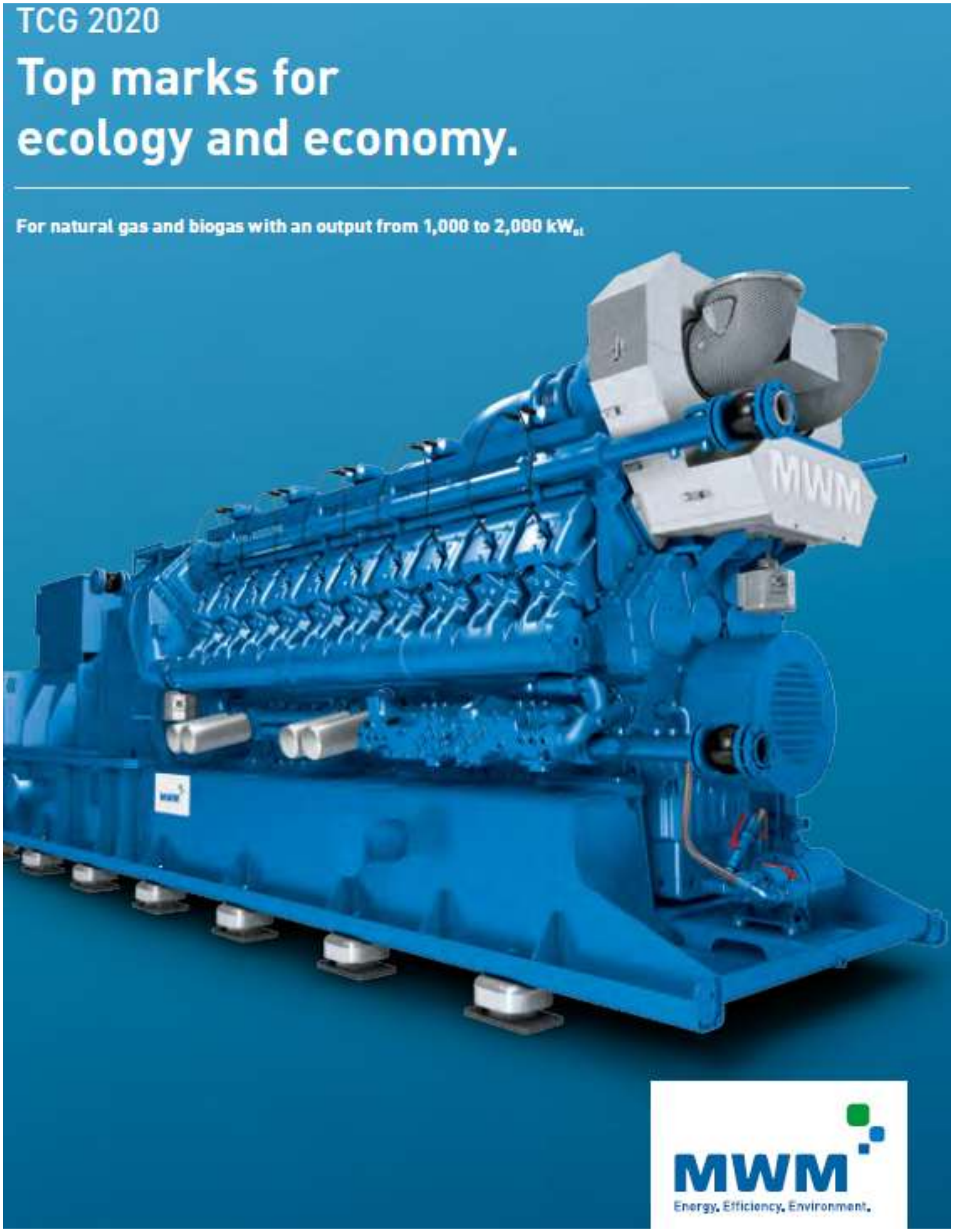
1) Transport dimensions of genset; components set up separately must be taken into consideration.
2) According to ISO 3046/1 at voltage = 11 kV, PF = 1.0 for 50 Hz, and a minimum methane number of MN 70 for natural gas, MN 130 for biogas.
3) Cooling of the exhaust gases to 120° C (248° F) for natural gas and 150° C (302° F) for biogas, plus engine jacket water heat.

NO_x emissions: Measured as NO_2 dry exhaust gas @ 5% O_2
Biogas fuels assumed to meet published engine-in contaminant limits with compositions:

Sewage gas (65 % CH_4 / 35 % CO_2)
Biogas (60 % CH_4 / 32 % CO_2 / 8% N_2)
Landfill gas (50 % CH_4 / 27 % CO_2 / 23% N_2)
Minimum heating value (LHV) = 18.0 MJ/Nm³ or 457 Btu/scf.
Specifications for special gases available.

Engine configuration with dry exhaust manifolds.
Data is representative and non-binding. Contact your Cat dealer for site and fuel specific performance.

APPENDIX V. **MWM TCG 2020 Biogas Generator Technical Specifications.**



Technical data 50 Hz

Engine type		TCG 2020	V12 K1 [1]	V12 K [1]	V12 [2]	V16 K [1]	V16 [2]	V20 [2]
Bore/stroke		mm	170/195	170/195	170/195	170/195	170/195	170/195
Displacement		dm^3	53.1	53.1	53.1	70.8	70.8	88.5
Speed		min^{-1}	1,500	1,500	1,500	1,500	1,500	1,500
Mean piston speed		m/s	9.8	9.8	9.8	9.8	9.8	9.8
Length [3]		mm	4,660	4,790	4,790	5,430	5,430	6,200
Width [3]		mm	1,810	1,810	1,810	1,810	1,810	1,710
Height [3]		mm	2,210	2,210	2,210	2,210	2,210	2,190
Dry weight genset		kg	11,200	11,700	11,700	13,300	13,300	17,900

Natural gas applications

$NO_x \leq 500$ mg/Nm³ [6]

Engine type		TCG 2020	V12 K1 [1]	V12 K [1]	V12 [2]	V16 K [1]	V16 [2]	V20 [2]
Electrical power [4]		kW	1,000	1,125	1,200	1,500	1,560	2,000
Mean effective pressure		bar	15.5	17.4	18.6	17.5	18.1	18.6
Thermal output [5]	±8 %	kW	1,177	1,253	1,190	1,675	1,580	1,977
Electrical efficiency [4]		%	40.0	40.9	43.6	40.9	43.2	43.7
Thermal efficiency [4]		%	47.0	45.6	43.3	45.7	43.8	43.2
Total efficiency [4]		%	87.0	86.5	86.9	86.6	87.0	86.9

Biogas applications

$NO_x \leq 500$ mg/Nm³ [6]
Sewage gas (65 % CH_4 / 35 % CO_2)
Biogas (60 % CH_4 / 32 % CO_2, rest N_2)
Landfill gas (50 % CH_4 / 27 % CO_2, rest N_2)

Minimum heating value H_u = 5.0 kWh/Nm³

Engine type		TCG 2020	V12 [2]	V16 [2]	V20 [2]
Electrical power [4]		kW	1,200	1,560	2,000
Mean effective pressure		bar	18.6	18.1	18.6
Thermal output [5]	±8 %	kW	1,194	1,577	2,012
Electrical efficiency [4]		%	43.0	42.6	43.0
Thermal efficiency [4]		%	42.8	43.1	43.3
Total efficiency [4]		%	85.8	85.7	86.3

1) Version optimized for standalone operation and load compensation.
2) Optimized efficiency version.
3) Transport dimensions for gensets, components set up separately must be taken into consideration.
4) According to ISO 3046/1 at U = 0.4 kV, cos φ = 1.0 for 50 Hz and a methane number of MN 80 (TCG 2020) or MN 70 (TCG 2020K) for natural gas.
5) Exhaust gas cooled to 120 °C for natural gas and 150 °C for biogas.
6) $NO_x \leq 500$ mg/Nm³, exhaust gas dry at 5 % O_2.

Data for special gas and dual gas operation on request.

The values given on these datasheets are for information purposes only and not binding. The information given in the offer is decisive.