Attachment L Materials for Technical Transfer for Biogas

Guideline for Biogas Generation

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Ministry of Energy and Petroleum

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Working Group of Biogas Guideline

Rural Electrification Authority (REA)

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List of Terms and Abbreviations

Abbreviation	Description
AC	Alternating Current
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
ERC	Energy Regulatory Commission
FIRR	Financial Internal Rate of Return
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
GoK	Government of Kenya
HH	Household
Hivos	Humanist Institute for Development Cooperation
IEE	Initial Environmental Examination
JICA	Japan International Cooperation Agency
KPLC	Kenya Power and Lighting Company Ltd.
KSh	Kenya Shilling (1US$ = 82.76 KSh, as of 1 September 2012)
LED	Light Emitting Diode
LPG	Liquefied Petroleum Gas
MoE&P	Ministry of Energy and Petroleum
NEMA	National Environment Management Authority
NGO	Non-Governmental Organization
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
PPOA	Public Procurement Oversight Authority
PPR	Polypropylene
PSDA	Promotion of Private Sector Development in Agriculture
PVC	Polyvinyl Chloride
RE	Renewable Energy
REA	Rural Electrification Authority
RT	Retention Time
SDR	Social Discount Rate
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organization)
ToR	Terms of Reference
USD	US Dollar
WB	World Bank
WG	Working Group of REA and JICA Expert Team

List of Electrical Terminology

A (Ampere)	Unit of current
V (Volt)	Unit of voltage
kV (kilovolt)	1,000 volts
W (Watt)	Unit of active power
kW (kilowatt)	1,000 watts
MW (Megawatt)	1,000kW
Wh (Watt-hour)	Unit of energy
kWh (kilowatt-hour)	1,000Wh
MWh (Megawatt-hour)	1,000kWh

EXECUTIVE SUMMARY

1. Background

Japan International Cooperation Agency (JICA) implemented the "Project for Establishment of Rural Electrification Model using Renewable Energy in Kenya" in 2012-2015. The project has two main components; (i) pilot projects for solar PV systems, and (ii) technical assistance for wind, small hydro, and biomass/biogas. This Guideline for Biogas Generation is prepared within the scope of the project by a Working Group (WG) of JICA Expert Team of Nippon Koei Co., Ltd /KRI in cooperation with Rural Electrification Authority (REA) in Kenya.

A biogas generation system is a method of electricity generation utilizing biogas produced by methane bacteria as the energy source. Similar to natural gas or propane gas, biogas has heat value, and can therefore be utilized as energy. Although the unit heat value of biogas is smaller than that of fossil fuels, biogas can be used as a cooking fuel in the same way as LPG with some modification of cooking stoves. When it is connected to a gas engine or modified diesel engine, it provides rotative force for the generator, producing electricity.

Since waste materials are used as feedstock for biogas systems and no fossil fuel is required, biogas is considered a renewable energy source.

In Kenya, more than 8,000 biogas digesters have been installed for use as a cooking fuel. However, experience in electricity generation using biogas is limited. This comprehensive Guideline is therefore prepared for future small scale biogas generation projects in Kenya.

Working Group of Guideline for Biogas Generation was formed to prepare the Guideline in the above project.

2 Objective of the Guideline

The Guideline is prepared for the sustainable planning, implementation, O&M, monitoring and evaluation of biogas generation systems for public facility electrification projects by Rural Electrification Authority, Kenya (REA). The intended readers of this Guideline are government and organization staff and users who will implement biogas generation projects. This Guideline can be utilized for site survey, planning, basic design, preparation of specifications, construction supervision, O&M, recording, and evaluation of biogas generation projects.

Strategic Master Plan 2013/2014-2017/2018 of Rural Electrification Authority (REA), Third Draft, stipulates that promotion of the use of renewable energy sources including biomass is one of REA's roles. In the strategic objective to develop and promote renewable energy sources, the strategic plan includes a target to develop and promote biogas and biomass systems for institutions and households.

The Guideline for Biogas Generation is therefore prepared for the reference for REA in the implementation of biogas projects in public facilities.

The targeted scale of biogas systems is digester volume up to 100 m^3 and biogas generators up to 20 kVA. This is a suitable scale for secondary schools with up to 1000 boarding students. For medium to large scale projects, i.e., more than 50 kW capacity, the planning, design, and O&M will be site specific, and is beyond the scope of this Guideline.. However, basic knowledge and requirements are common and can be utilized regardless of the scale of biogas projects being implemented.

3. Structure of the Guideline

The Guideline consists of the following three sections:

- ✧ Part-I Guideline for Biogas Generation Planning
- ✧ Part-II User Guideline for Biogas Generation Operation
- ✧ Part-III Guideline for Monitoring and Evaluation

Part-I is prepared for government and related organization staffs who are in charge of studying, planning, designing, evaluation, and procurement of biogas generation system. The main target of the guideline is for public institutions such as schools, which has replicability of various projects. Large private-base projects require specific planning and design, which should be formulated in respective feasibility study, and those are not the target of this Guideline.

In Part-I, Chapter 1 is about overview of biogas system. Chapter 2 is about basics of biogas system that the staff should know, including anaerobic digestion and methane fermentation, microbiology, typical system model, project flow, and lessons learned from past projects. Chapter 3 summarizes requirement to conduct site survey.

Chapter 4 is about details for basic planning including method for feedstock assessment, calculation of possible amount of biogas production from feedstock, calculation of fuelwood and electricity saving amount, demand assessment, and determination of system layout.

Chapter 5 is prepared for design of biogas system, which includes selection of biogas digester type, design of digester and related facility, design of pipe and water trap, and basic requirements of biogas engine generator and biogas stoves.

Chapter 6 describes about method of cost estimation. Chapter 7 includes detail methods for financial and economic evaluation for public projects including preparation of cash flow and internal rate of returns (IRR).

Chapter 8 is for procurement and construction supervision, which includes procurement procedure, qualification, and detailed specifications that the Contractor should observe for biogas system construction. The items for construction supervision should be modified according to specific system design.

Chapter 9 is for environmental consideration and necessary clearance procedure that the project proponent should follow.

Part-II is prepared for the users of biogas generation system in facilities. This part includes general description about biogas system operation and maintenance. Biogas digester type and generator sets will depends of manufacturers, and user manual from respective manufactures should be obtained and given to the user together with this part of the Guideline.

In Part-II, Chapter 1 is overview for the user manual. Chapter 2 describes components of biogas system for understandings of users. Chapter 3 includes operation and maintenance items that the users need to conduct, including starting, daily routine works, periodical works, utilization of effluent, and maintenance of tools.

Chapter 4 is about recording that user should conduct in operation and maintenance works. This will be the base data for evaluation. Chapter 5 is about safety requirement of biogas system that the users should know and follow.

Chapter 6 summarizes DOs and DON'Ts and trouble shootings. This is about general description, and specific items for biogas system, and specific items should be provided from the contractor and supplier.

Part-III is prepared for the staffs who conduct monitoring and evaluation, such as government, founder, and donor agency. This part includes items and method for monitoring and evaluation.

In Part-III, Chapter 1 summarizes necessity of monitoring items, monitoring tools, and format for monitoring. Chapter 2 describes methodology and necessary data for technical evaluation, economic evaluation, and financial evaluation. Example of financial and economic analysis using assumed data is included in the chapter.

Chapter 3 is for environmental management that should be conducted during monitoring.

4. Acknowledgment

The authors thank to Mr. R.Hoffman and staffs of GIZ for provision of information and materials and allowing to utilize drawings and materials in this Guideline.

GUIDELINE FOR BIOGAS GENERATION

PART-I
GUIDELINE FOR BIOGAS GENERATION SYSTEM PLANNING

PART-I GUIDELINE FOR BIOGAS GENERATION SYSTEM PLANNING

CHAPTER 1 OVERVIEW

1.1 Biomass and Biogas

Biomass is the organic material which is utilized as energy. The word "biomass" refers to the mass of material originating from biological sources. When biomass is referred to as an energy source, it's derived mainly from agricultural, industrial, and public organic wastes which are not considered as valuable resources.

Biomass is an organic alternative source of energy that reduces carbon dioxide (CO_2) emissions. Since biomass assimilates CO_2 from air, it is considered a carbon neutral source of energy. The carbon dioxide released into the atmosphere when using biomass is reabsorbed by the growth of new biomass.

There are several techniques of biomass application for energy production, as shown in the table below.

Table 1.1.1 Types of Biomass Application Techniques

Type	Description	Advantage	Disadvantage
Direct combustion	Biomass is burned and generates pressurized steam. This rotates the engine and generator, producing electricity. Feasible in the scale of MW.	Proven technology, same as thermal power.	Moisture content needs to be low. Massive biomass collection is required for scale merit.
Biomass gasification	By pyrolytic decomposition of organic material, CO and H_2 are generated. This rotates the engine and generator. Suitable for 10-100kW scale.	It can be applied to small industries such as rice milling and is applicable to rural electrification.	Bulk biomass collection is necessary. Moisture content needs to be low. Efficiency is low (7-10%)
Biodiesel/SVO	Esterified vegetable oil or straight vegetable oil can be used as a fuel in diesel vehicles and for diesel generation. Non-food products such as Jatropha are being tested.	Application to both rural electrification and the transportation sector is possible.	Scale merit required at the 10,000 ha scale of land for financial feasibility. Concern over food-energy security is an issue. Non-food products are a challenge in terms of cost.
Bioethanol	Decomposed organic materials produce ethanol. This can be used as an alternative to petroleum (gasoline)	Ethanol can be used in petrol cars and small generators (1-5kW)	Scale merit requires 10,000 ha scale of land for financial feasibility.
Biogas	Produced by methane fermentation in anaerobic sealed condition, methane gas is used as a cooking fuel and for generation.	Best source of energy, as an alternative to fuelwood. Generation is possible using modified gas/diesel engines (1-200 kW)	Biomass collection is necessary. Large scale application is difficult.

Usually, scale merit is necessary to ensure the biogas project is financially feasible. However, in rural areas, there are no large industries producing large amounts of organic wastes expected. Biomass collection is therefore always a challenging issue, leading many projects to experience hardships or even failure due to difficulty of biomass collection. On the other hand, public institutions such as schools with dormitories and prisons inherently collect human waste using sewer systems. Cow dung is also available in most cases, and it is a good source of biogas.

Accordingly, biogas is selected as the most suitable form of biomass energy for application in rural areas.

1.2 Biogas as Energy Source

Biogas is a fuel gas produced by anaerobic fermentation of organic material by methane producing bacteria. Methane is produced in strictly anaerobic (oxygen-free) sealed conditions by particular bacteria consortium.

Biogas has the following characteristics.

- Generally, it contains 50-70% methane,
- Major gas component is methane (CH_4), CO_2 and H_2O,
- Minor gas component is H_2, N_2 and H_2S,
- Biogas can be used as cooking fuel and for electricity generation, and
- It is carbon neutral

Biogas has calorific value similar to LPG and natural gas, although the value is only about half of that of fossil fuels. Biogas can be utilized in the same way as LPG or natural gas when modified cooking stoves or modified engine-generators are applied.

The comparison of fuels and biogas is shown in the table below.

Table 1.2.1 Comparison of Fuels and Biogas

Fuel Type	Value	Unit	Form
LPG	92-94	MJ/m^3	Gas
Methane	35.9	MJ/m^3	Gas
Natural gas	37-39	MJ/m^3	Gas
Kerosene	36.7	MJ/L	Liquid
Diesel oil	37.7	MJ/L	Liquid
Coal	22-26	MJ/kg	Solid
Biogas	20-30	MJ/m^3	Gas
Firewood*	10-20	MJ/kg	Solid

* Depending on type and moisture content

CHAPTER 2 BASICS OF BIOGAS

2.1 Anaerobic Digestion

Anaerobic digestion is a biological process during which complex organic matter is decomposed in the absence of oxygen, by various types of anaerobic microorganisms.

Knowledge of the fundamental processes involved in methane fermentation is necessary for planning, building and operating biogas plants. The process of biogas production depends on various parameters such as temperature, concentration of materials and pH. These conditions significantly affect bacterial activity.

Aerobic and anaerobic conditions can be assessed by redox potential or oxidation-reduction potential (ORP) (Eh). During the succession of anaerobic oxidation processes, the redox potential of flooded soils and liquids will decrease as a result of the reduced products formed.

Redox potential can be measured by a handy ORP meter with a unit of mV. Approximate values for redox potentials associated with specific oxidation-reduction processes are shown in the table below.

Table 2.1.1 Redox Potential, Eh, and Reaction

Observation	Eh (mV)	Reaction
Aerobic respiration	>+330	$1/2\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$
Denitrification	+330 to 220	$2NO_3^- + 12\ H^+ + 10e^- \rightarrow N_2 + 6H_2O$
Manganese reduction	+220- 200	$MnO_2 + 4H^+ + 2e^- \rightarrow Mn^{2+} + 2H_2O$
Ion reduction	+200 to 120	$Fe(OH)_3 + 3\ H^+ + 2e^- \rightarrow Fe^{2+} + 2\ H_2O$
Sulfate reduction	+120 to - 150	$SO_4^{2-} + 10H^+ + 8e^- \rightarrow H_2S + 4\ H_2O$
Methane production	-150 -250	$CO_2 + 8\ H^+ + 8e^- \rightarrow CH_4 + 2\ H_2O$

Source: http://microbewiki.kenyon.edu/index.php/Flooded_soils

By knowing redox potential, anaerobic condition for methane fermentation can be checked.

Methane production occurs exclusively in anaerobic conditions by a group of Archaea known as methanogens. These microbes are essential, and require extremely low redox conditions in the range of -100mV. If oxygen is introduced into the system, methane producing bacteria will die. In actual conditions of the digester, the surface of effluent exposed to air will contain a small amount of oxygen, which helps decomposition of complex materials by other bacteria.

2.2 Microbiology for Methane Fermentation

The process of methane production is effected by byproducts produced from a complex series of degradation processes. Byproducts are derived from the degradation of complex organic matter.

For methane production from feedstock biomass, complicated degradation processes occur. Biomass is decomposed to glucose, amino acid, etc., which are further degraded into lower carboxylic acid such as butyric acid, propanic acid and acetic acid.

Methane production can occur via one of two pathways, either by 1) CO_2 reduction or by 2) acetate fermentation.

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

by methane bacteria utilizing acetic acid, such as *Methanosaeta concilii, Methanosarcina barkeri* and *Methanosarcina thermophila*

2) $CH_3COOH \rightarrow CH_4 + CO_2$ (acetate fermentation)

By methane bacteria utilizing hydrogen such as *Methanobacterium formicicum, Methanothermobacter thermautotrophicus* and *Methanococcus voltae*

Both acetate and hydrogen are byproducts of anaerobic fermentation.

The mechanism of methane fermentation is summarized in the figure below.

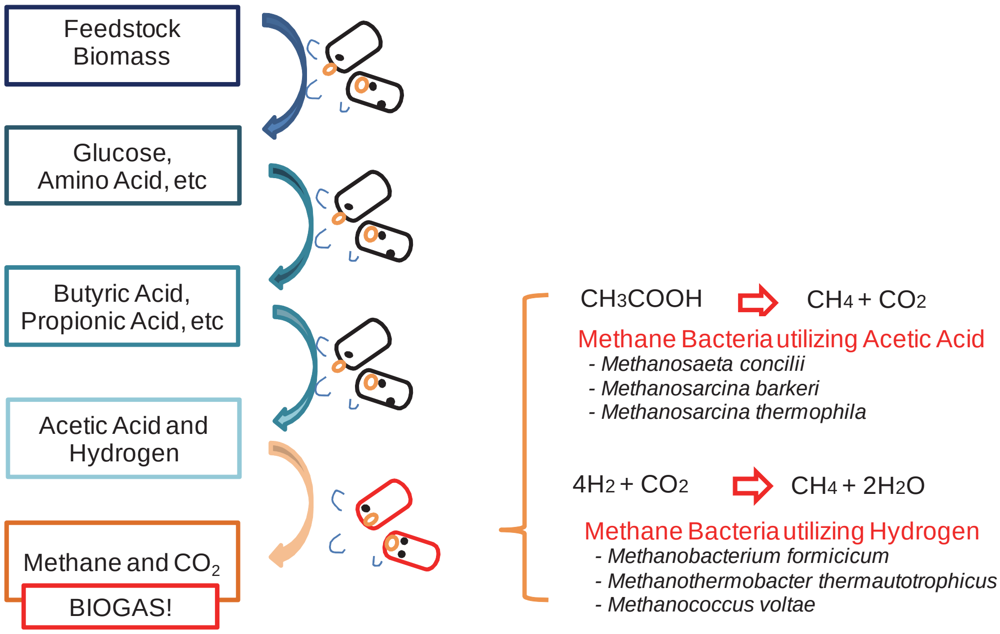


Figure 2.2.1 Basic Mechanism of Methane Fermentation

The rates of methane production are highly sensitive to temperature changes.

To digest organic materials, the above complex reactions occur in the biogas digester. Accordingly, the biogas digester contains various layers of redox potential .

Generally, sulfate reduction also occurs in the biogas digester, producing hydrogen sulfide. Hydrogen sulfide needs to be removed since it is corrosive and damages pipes, valves, meters, and engines and generators.

2.3 Feedstock Types for Biogas System

Theoretically, all organic materials can be used for methane fermentation. However, if the molecular composition is complicated, e.g. cellulose, it requires longer fermentation time and a complicated system which includes hydrolysis for degradation.

The feedstock for biogas production must be biodegradable material. If feedstock contains materials whose molecular structure is complicated, it cannot be degraded in an anaerobic digester. Complex materials such as protein and fat require a hydrolysis aerobic process before entering the anaerobic digester. For such systems, motive power such as pumping is required for transportation of feedstock and provision of air. Such complicated systems are not ideal for biogas in public institutions or remote areas.

Feedstock for biogas, especially in public facilities in rural areas, requires the following aspects:

- Energy input for operations such as electricity for pumping should be minimized
- Design should be developed ensuring that O&M is minimized.
- System should be as simple as possible

Substrate and material balance in biogas production needs to be considered in planning. In principle, all organic materials can ferment or be digested. However, only simple liquid substrates can be considered for use in simple biogas plants: feces and urine from human and livestock such as cattle. Waste and wastewater from food-processing industries are suitable for simple plants, but can only be used if they are homogenous and in liquid form.

Cattle, especially, inherently contain methane producing bacteria in their stomachs and dung. Cow dung is therefore the most preferred feed stock for biogas generation.

Utilization of animal manure and slurries as feedstock for anaerobic digestion has some advantages due to their properties:

- The naturally present and high content of anaerobic bacteria
- The high water content (4-8% dry material in slurries), acts as solvent for the other substrates and ensures biomass mixes and flows properly
- The high accessibility, and ease of collection as a residue from animal farming

Accordingly, the following materials are considered for the design of biogas systems in this Guideline.

- Human waste
- Livestock manure (cow dung, pig manure, etc.)

Most of schools have cows for daily milk supply in the facilities. Density of cow in Kenya is shown in the figure below.

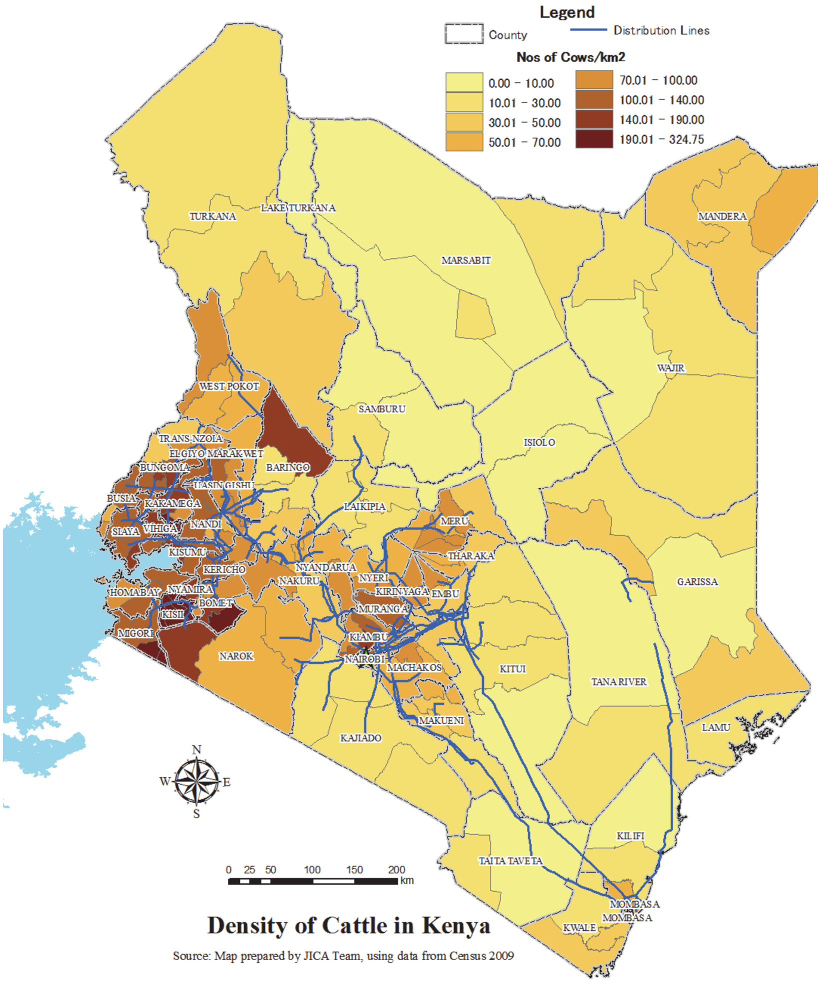


Figure 2.3.1 Cattle Density (Number of Cows per km^2)

2.4 Concept of Biogas System Model

For the implementation model of biogas as government project, facilities such as schools with dormitories or prisons have advantage in terms of the following:

- Human waste is collected via a sewer system and septic tank
- Generally schools have dormitories and own cows for milk supply. Cow dung is the best source of biogas.

The system model is illustrated in the following figure.

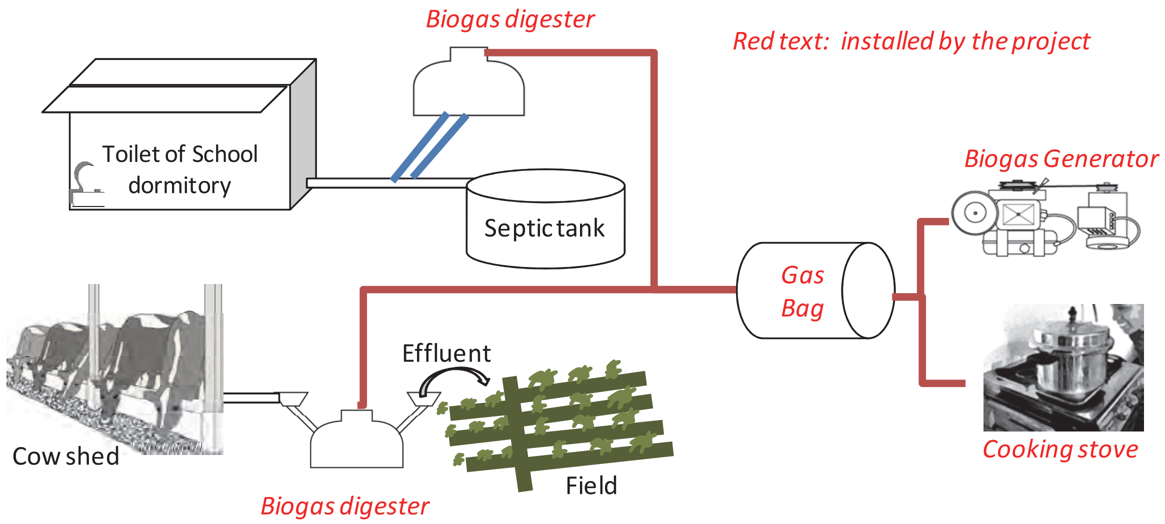


Figure 2.4.1 Basic Concept of Biogas System

The outline of the system is as follows:

1) Human waste is collected in a septic tank. The biogas digester is installed between the toilets and septic tank, with effluent from the digester entering the existing septic tank. After methane production, solid waste, BOD and pathogens will be reduced in the digester, reducing the organic load to septic tank.
2) Cow dung from the cow shed is collected in the digester through a trench. After degradation and methane production in the digester, effluent can be used as fertilizer to increase yield of garden vegetables and feed. The feed will be supplied to cows, thereby enabling material cycle while producing biogas energy.
3) Biogas produced in the digester is collected in a gas bag, and can be used for either generation using a biogas generator or directly in cooking stoves, or both.

For successful application of the biogas system, proper management of human waste is necessary, which include prevention of detergent, sanitary waste, water content, etc.

2.5 Component of Biogas and Calorific Value

There are various units used in statistics, physicality tables, project documents, and academic papers for values related to biogas. For the assessment of biogas potential and benefit, it is necessary to convert values into the same unit.

The joule (symbol: J) is a derived unit of energy, work, or amount of heat in the International System of Units. One joule is equivalent to 1 Watt x 1 Second. Joule is used for heat value of fuelwood and fossil fuel.

Calorie (symbol: cal) is the approximate amount of energy needed to raise the temperature of one gram of water by one degree Celsius. Calorie is mainly used for heat value of food.

Watt-hour (symbol: Wh) is the unit for electric energy. One watt-hour is equal to 3,600 x 1 Watt-second, which is equivalent to 3,600 Watt-second.

The following are the typical conversions.

1 J = 1 kg·m²/s² = 1 Ws (Watt-second) = 0.239 cal = 0.000278 kWh

1Wh = 3600 Ws = 3600 J = 860 cal

The following table summarizes the conversion of calorific values and electric energy.

Table 2.5.1 Conversion Table of Jule, Watt-hour, and Calorie

	J	kWh	Cal
1 J	= 1 kg·m²/s²	$\approx 0.278\times10^{-6}$	≈0.239
1 kWh	= 3.6×10^{6}	1	$\approx 0.860\times10^{6}$
1Cal	= 4.1868	$\approx 1.163\times10^{-6}$	1

1MJ =0.278 kWh

2.6 Project Flow of Biogas Generation

General flow to implement a biogas project is shown in the figure below.

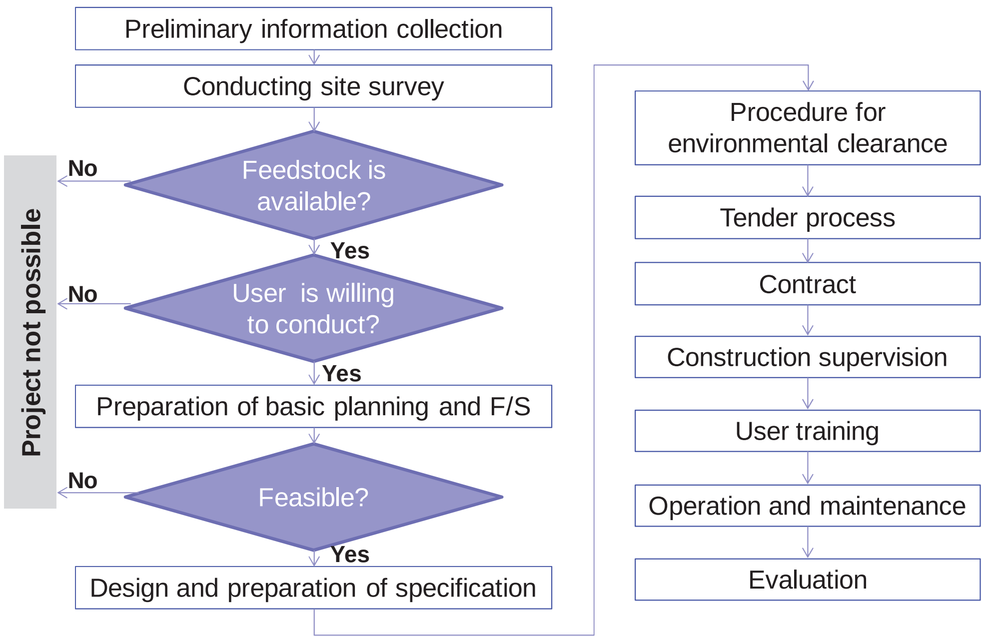


Figure 2.6.1 Flow of the Project

Willingness of project owner and indicative availability of feedstock is confirmed in the preliminary information collection stage

In the site survey, necessary data such as quantity of feedstock, layout of facility and current cost of fuel is collected to conduct cost estimation and economic analysis.

Feasibility study is conducted so that the funding agency can determine if a project is feasible or not.

Once the project is evaluated and determined to be feasible, design and specification is prepared.

At the same time, environmental compliance procedures are undertaken with NEMA, such as preparation of project description paper, procurement of lead expert, preparation of project document as Initial Environmental Examination, and obtaining clearance from NEMA.

After tendering and entering into a contract with a contractor, it is necessary to supervise construction, test equipment and conduct user training on operation and maintenance.

It is necessary for data collection to be conducted by the user for proper monitoring and evaluation.

2.7 Lessons Learned from Past Biogas Project

The use of biogas as a household cooking fuel is prevalent in Kenya, with over 6,000 biogas digesters thought to be installed countrywide. However, application of biogas technology for power generation still poses a challenge in terms of technical and management aspects.

For the successful implementation of projects, technical aspects have to be adequately considered. This includes components such as project planning, design, construction supervision, testing, and operation and maintenance. However, these are still under development through trial-and-error.

The main issues and challenges in sustainable operation of biogas projects are as follows:

- Lack of an overall manager and trained technicians with adequate background knowledge on the projects.
- Lack of support structures such as linkages to other organizations and suppliers of spare parts at the time of trouble shooting
- Selection of feedstock unsuitable for anaerobic digestion, for example, banana stems.
- Lack of records such as operation manuals and data logs for system performance and business accounts.

The following key lessons have been derived from past experiences in biogas projects:

- In addition to the overall manager, at least two technicians should be adequately trained during the construction and installation phase. The training provided by the contractor should be monitored by the supervisor as well.
- Appropriate feedstock should be selected for biogas production through anaerobic digestion.
- The biogas generation system should be as simple as possible for easy O&M. Complicated hydrolysis process should be avoided in the case of public institutions and rural areas.
- In addition to the technical aspects, capacity building in management including data recording and accounting is important, and should be addressed adequately in the training.

In 2011, REA implemented two pilot biogas projects with generation facilities. Lessons from those biogas projects are as follows:

- Design component
  - ✧ Sufficient difference in elevation of the channel, to transport the cow dung effluent by gravity is necessary.
- Digester connected to toilets
  - ✧ The effluent from toilet digesters may contain helminth eggs or coliform. It can be utilized as fertilizer only when adequate care is taken.
  - ✧ The quantity of water used to flush the toilets should be limited (about 1L/person/time). This should be well explained to users.
  - ✧ Detergents with Chlorine should not be used for cleaning the toilets. Only biodegradable detergents should be used for cleaning purposes.

  - ✧ One toilet which is not connected to the digesters should be assigned to students taking medication to prevent antibiotics from entering the digester.
  - ✧ For girls' school, management of disposal of sanitary towels is necessary to prevent such waste from entering the digester.
- Construction Supervision
  - ✧ It is necessary to include provision of user training, manual and drawings, and testing and commissioning in the contract with a contractor.
  - ✧ Full-time supervision for approval of construction quality and documentation is necessary. Exclusive staff for supervision should be assigned.
  - ✧ It is necessary to check for gas leakage throughout the pipe line and gas bag. Checking of the pipe route before backfilling is necessary.
- User O&M
  - ✧ Prohibition of potential fire hazards should be strictly applied
  - ✧ User participation in planning and construction supervision is necessary as well as training for O&M.
  - ✧ Use of cow dung as feedstock in addition to human waste is recommended for favorable bacteria for biogas generation.

For the planning of biogas projects, the above aspect should be considered sufficiently.

CHAPTER 3 SITE SURVEY

3.1 Preparation of Site Survey

The objective of the site survey is (i) to confirm willingness to implement the biogas project and ask the user for cooperation in system planning, installation, and operation and maintenance, and (ii) to collect basic information necessary for basic planning and feasibility study.

The followings are the prerequisite items before conducting a site survey of the biogas generation system.

- Collection of information on existing facilities from Ministries and local government
- Confirmation of location and road condition on the map
  - ✧ Using google map/earth and identifying coordinate (latitude and longitude) makes the survey easier.
- Appointment for facility manager
  - ✧ Appointment with technicians or staff who manages cows and toilet facilities is preferred.
- Preliminary introduction and interview about the willingness of the project over the phone
- Preparation of tools to bring: digital camera, GPS, measuring tape, sketch book, interview sheet, distance meter and booklet about biogas for explanation

3.2 Site Survey Items

It is necessary to conduct a site survey in order to collect data and information for basic planning and feasibility study in detail. The following items need to be confirmed at the site survey.

- Location
  - ✧ Facility name, address, coordinate, elevation, map etc.
- Infrastructure
  - ✧ Surrounding road condition, distance from Nairobi, power supply condition, water supply condition
- Facility data
  - ✧ Financed by, organization structure, establishment year, name and contact of manager and key staff, geological structure, salary level of staffs, operation hours, etc.
- Possible amount of feedstock
  - ✧ Number of cows, pigs, poultry, etc., number of students, quantity of raw materials, etc.
- Possible location of system
  - ✧ Digester, generation system, pipe layout, effluent supply, etc.
- Facility layout
  - ✧ Layout of facility, sketch or map of buildings inside the facility, location of toilet & septic tank, cow/pig/poultry shed, location of kitchen, etc.
- Usage of effluent
  - ✧ Location of garden, area of garden and type of vegetables
- Current usage of energy (demand analysis)
  - ✧ Availability of diesel engine generator and condition of usage

- ✧ Consumption and cost of fuelwood, electricity, LPG gas, diesel oil, electricity tariff, etc.
- ✧ Electricity bills (for one year, if possible)
- ✧ Current electric appliance and type of lighting

· Priority of biogas usage

- ✧ Electricity, cooking fuel, or LPG

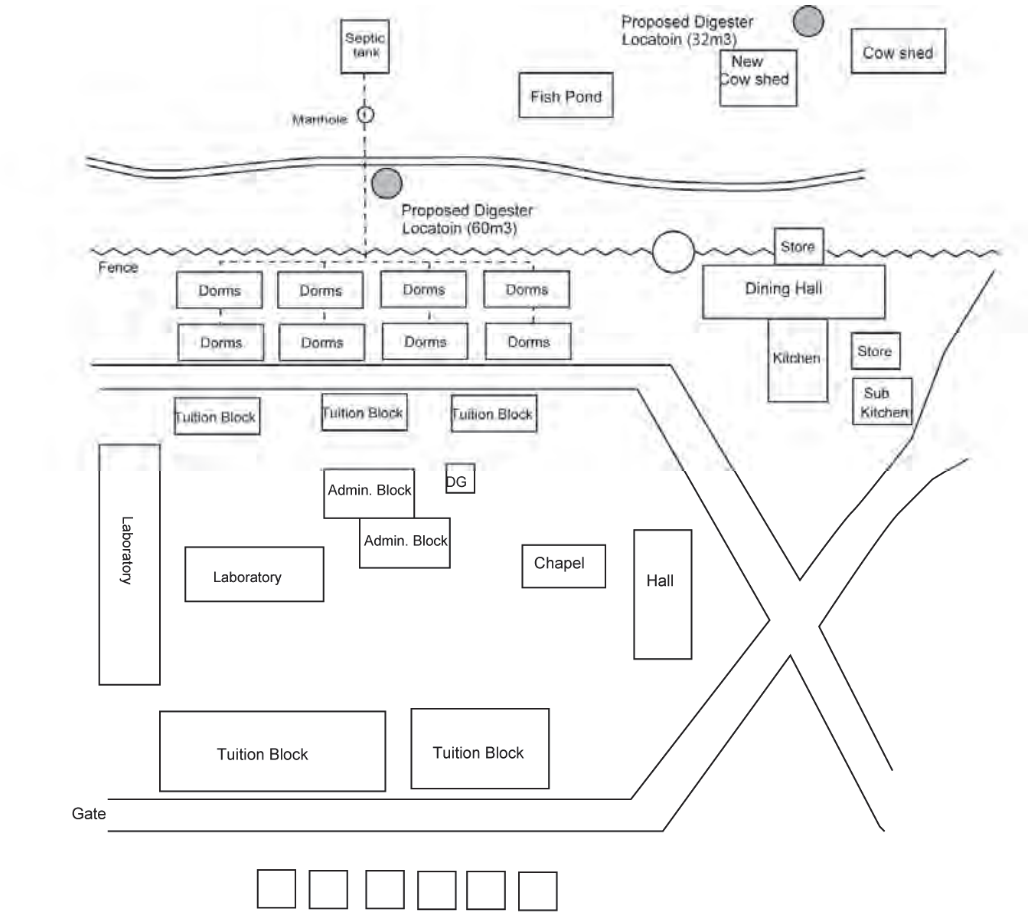
· Photos

- ✧ Cow shed, garden, toilet, dormitory, existing electric facility, location of digester, etc.

A sample survey result is shown in the table in the next page.

The form for the survey is provided in Annex-1.

A sketch of the facility needs to be prepared during the survey, showing the proposed digester location. The figure below is a sample facility sketch showing the layout of buildings and location of digesters.



This layout is prepared based on a rough sketch and scale is not propotional to actual sites.

Figure 3.2.1 Example of Facility Sketch with proposed Digester Location

Table 3.2.1 Example of Information Collection Sheet for Survey of Biogas Generation System

Confirmation Items for Biogas Generation Planning

Confirmed by: Caroline Kelly and Y. Nakagawa **Date: 23 May 2013**

Confirmation Item	Unit	Nyeri High School	Rware High School
Basic Information			
Date of site survey		23/05/13	23/05/13
Name of the facility		Nyeri High School	Rware High School
Location (County, sublocation, location, village)		Nyeri County	Nyeri County
Coordinate (Latitude, longitude, elevation)		N° 24.499', E36° 55.159', EL1844m	N° 24.793', E36° 57.323', EL1786m
Distance from Nairobi		168 km (paved, except last 1 km)	158 km (paved)
Grid connected?, Nearest grid connection in km		Yes	Yes
Financed by		Missionary, government, PTA	Government
Establishment year		1924	1985
Major ethnic group		Mixed	Kikuyu, Meru
Name of manager (principal, teacher, head, etc)		Mr. Nderity (Principa), Mr. Muturi (Deputy Principal)	
Organization structure		Attach	Attach.
Availability of technician and operator		Available	Not abailable, need to hire
Type of geology, geological structure		reddish soil	reddish soil
Salary level of staffs		10,000kSh/m for cook, 250 Ksh/day	
Operation hours		Day class 8:10-16:00, night class 19:30-22:00	Day 7:00-17:30 (no night class)
Contact address and number		Mr. Paul Wanjohi, wndiritup@yahoo.com http://www.nyerihigh.com/	Ms. Elizabeth Juma 0723580546 lizjuma@ymail.com rware@ymail.com
Possible feedstock input			
Nos of cows	nos	5 cows, 1 midium, 4 smal, total 10. 2 cows in different cow shed. Possibe to increase.	9 cows
Nos of pigs or nos of pultry	nos	NA	NA
Nos of students (total)	nos	950 students (all boarding)	400 boys, 200 girls, total 600 students
Nos of students (boarding, period of boarding)	nos	950 students, 13 weeks leave/yr	none (all daily students)
Nos of teacher and staff	nos	40 teaches and 30 non-teaching staff	25 teachers and 15 non-teaching staffs
Nos of teacher (living)	nos	40 teaches and 30 non-teaching staff	None
Type of toilet		Septic tank available	Pit laterine
Water usage for toilet cleaning	L/day, t/day	30 t/day	
Raw waste material (food, vegetable waste, etc)		Kitchen waste	
Garden or caltivation near the site		Naipier(5acre), sweet potate(0.5acre), Maise(0.25acre), glass(2acre), Tilapia fish pond Feeding 2 t/day	bean, banana, grass land, total 2 acres
Current energy usage			
Electricity usage	kWh/mon	TBA	Approx. 1000 kWh/m
Electricity tariff payment record (invoice for several months)	Ksh/mon	Ave. 130,000 Ksh/m, 5000 kWh/m 147,680KSh with 7,605 kWh (Mar 13)	8974 KSh with 1028 kWh (Feb 13)
Current use of electric/heat appliance (type, hours) Light, PC, mobile charge, TV, radio, cooking heater, other		General electric appliance, lighting Total 59 nos of 36W FL bulb in dorm.	General administration, lighting, cooking. PC is planned to be installed.
Diesel generator and oil for generation, if any, cost	L/day, L/mon	38.5 kVA, 480L/year	None
Type of fuel for cooking (Fuel wood, LPG, etc)		Fuel wood, LPG (45kg/term)	Fire wood.
Current usage of fuel wood, cost	kg/day, t/mon	300 t/year, 792,857 Khs/year	42 t/term, 3300 Ksh/t -> 415,800Ksh/yr
Current usage of LPG, cost	cylinder/mon	TBA	None
Current usage of other fuel		Boiler by firewood	None
Source of water supply (pump, etc.)		Municipal water, gravity from river 12 away	Municipal water
Type of lighting		Eectricity	Eectricity
Priority usage of gas (electricity, fuel, etc)		1) cooking fuel, 2) lighting for dormitory and night class	1) cooking fuel
Other Remarks		Japanese assistance for Math and Science was taken in 2004 through Min of Education. 22 buildings of Teacher Quarter.	

3.3 Users' Involvement

From the time of the survey, it is important to provide a detailed explanation to the school manager and obtain commitment of cooperation for project implementation. The following items need to be explained and endorsement should be obtained before planning begins.

- Assignment of project manager
- Participation in preparation for planning

- Conducting construction supervision
- Undertaking user training provided by contractor (by at least three operators)
- Hiring staff to conduct operation and maintenance
- Monitoring, recording and data provision for evaluation

It is important to include users at all stages of the project; survey, data and information collection, planning, preparation of layout, cost estimation, construction supervision, testing and commissioning, receiving training, and O&M plan. Involvement of users from the early stages of project formulation enhances the sustainability of the project. It is essential that the users have a sense of ownership, as the key player responsible for the overall project. A project manager should be assigned who will take responsibility from user facility.

The responsibilities of a project manager of the users include the following:

- Guidance about the facility during survey
- Information and data provision for planning
- Understanding of technical aspects of biogas systems
- Review and endorsement of plans including design and cost estimation
- Supervision and checking of quality of works and constructions by a contractor
- Assignment and management of technician(s) for O&M
- Participation in training alongside technicians
- Monitoring and data collection for operation and recording of problems and repair
- Reporting about monitoring

CHAPTER 4 BASIC PLANNING

4.1 Items for Basic Planning

Basic planning is conducted at the initial stage of the project to determine the scale of the system, overall demand and possible energy supply, and cost estimate. The following items need to be examined for purposes of basic planning.

- Project objective
- Assessment of available feedstock
- Amount of biogas production
- Benefit from fuel saving
- Demand assessment
- Determination of system layout
- Design
- Utilization of effluent as fertilizer
- Cost estimation

The above information is used to determine whether the system is worth implementing in terms of cost and benefit.

4.2 Assessment of Available Feedstock

As explained in Chapter 2.3, the system for a rural facility should be as simple as possible. It is necessary to select materials that can be degraded in an anaerobic digester only, that is, livestock dung and human waste.

(1) Cow dung and livestock dung

The number of cows available is the most predominant indicator of possible amount of biogas production. The following items need to be considered when assessing available amount of cow dung.

- Average weight of cows should be assessed. If the cows seem to be small or slim, average amount of cow dung needs to be adjusted considering actual weight of the cows.
- Future plans to increase the number of cow needs to be considered. The system should be designed to cover maximum possible number of cows in the facility.

Other wastes from livestock may include pig dung. However, to assess whether it is applicable, location of livestock shed and connection accessibility to a digester need to be considered. In case any of the following situations are is observed, other livestock wastes should not be included in the plan.

- Required trench to connect to digester is too large (>100 m)
- Livestock shed is located below the location of digester
- Number of livestock is too small (less than 10)

(2) Human waste

Only human waste connected to septic tanks can be considered as the applicable feedstock for a digester. If the toilet is a pit latrine and waste is isolated and dispersed, it cannot be considered as feedstock unless a sewer line connecting to the digester is constructed. The following items need to be confirmed through a survey.

- Number of students at the school
- Frequency of use for each toilet at the school. If it has pit latrines and an isolated septic tank, those should not be connected to the digester.

- Average age of children and difference in weight from adults

The above items should be considered in utilization ratio. If utilization ratio is 100%, it means one adult person fully uses a toilet connected to a digester with septic tank. If students' weight is not as much as adults, or if they use a different toilet in a day which is not connected to the digester, that percentage needs to be evaluated to reduce utilization ratio.

The following table can be used to assess amount of feedstock.

Table 4.2.1 Items to assess Amount of Feedstock for Biogas

Possible feedstock input	
Nos of cows	nos
Nos of pigs or nos of pultry	nos
Nos of students (total)	nos
Nos of students (boarding, period of boarding)	nos
Nos of teacher and staff	nos
Nos of teacher (living)	nos
Type of toilet and percentage of use for each type	
Water usage for toilet cleaning	L/day, t/day
Raw waste material (food, vegetable waste, etc)	
Garden or caltivation near the site	

4.3 Amount of Biogas Production

4.3.1 Amount of Biogas from Cow Dung and Livestock Waste

The expected amount of biogas production from cow dung, pig dung, and poultry waste is shown in the table below.

Table 4.3.1 Amount of Biogas Production

Type of feedstock	Waste Amount per nos kg/nos 1)	Gas Production per Waste kg m^3 /kg Experiment in Uganda 2)	Gas Production per Waste kg m^3 /kg Experiment in Nigeria 3)
Cattle (cows and bullocks)	16-24	0.023-0.04	0.037
Pig	1.9-2.5	0.04-0.059	0.058
Poultry	0.075-0.1	0.065-0.116	0.069

Source:
1) http://ishikawa.lin.gr.jp/kankyo/02.htm
2) Biogas as an alternative to fuelwood for a household in Uleppi sub-country in Uganda
3) S.J. Ojolo, et al, UTILIZATION OF POULTRY, COW AND KITCHEN WASTES FOR BIOGASPRODUCTION: A COMPARATIVE ANALYSIS Iranian Journal of Environmental Health Science & Engineering,Vol.4, No. 4, 2007, pp. 223-228

The above table shows the amount of feedstock (dung) production in kg per livestock by type, and amount of gas production in m^3 per kg of feedstock. The values vary depending on the weight of livestock and feeding conditions. It is necessary to consider the average weight of livestock and feeding conditions. For example, if the average weight of cows seems typical and their feeding condition is mild, the middle value in the above table can be applied.

Example-1: Biogas production by 15 cows

15 cows x 20 kg/cow x 0.033 m^3/kg= 9.9 m^3

Example-2: Biogas production by 100 pigs

100 pigs x 2.0 kg/pig x 0.05 m^3/kg = 10 m^3

The amount of biogas production per kg of cow dung was measured at 0.023-0.04 m^3/kg (Gunter U, 2011). For general assessment by calculation, and applying the average of this experimental value, biogas production volume per cow is estimated using the following formula:

$$V_c = 0.033N_c \times W_d \times 365$$

Where, V_c: Volume of biogas production from cow dung (m^3/year)
N_c: Number of cows in facility
W_d: Average cow dung production (kg/cow)

The value W_d varies depending on cow conditions such as age, weight, nutrient status, etc. Here, 20 kg/cow is applied.

4.3.2 Amount of Biogas Production from Human Waste

The amount of biogas production from human waste is estimated at 0.02-0.028 per adult human, based on past experiences. The size of digester can be determined to be 0.1 m^3per person per day.

Table 4.3.2 Amount of Biogas Production from Human Waste

Description	Value	Unit
Amount of biogas production [1)]	0.02-0.028	m^3/person/day
Size of digester	0.1	m^3/person/day
Substrate	3.3-4.9	L/person/day
faeces	0.25-0.4	kg/person/day
urine	1-1.5	L/person/day
flushing water	2-3	L/person/day

1) Biogas as an alternative to fuelwood for a household in Uleppi sub-country in Uganda

The above data for the substrate are reference values only, and the amount of biogas production varies depending on the average weight of users of the facility.

In addition, if the system is installed in a school, the following parameters should be considered to assess total amount of annual biogas generation:

- The weight of students is not as much as adults.
- If the target facility has toilets which are not connected to the digester, such as pit latrines, usage ratio for toilets connected to a digester should be assumed.
- If the school has off-days and holidays without students at the facility, the rate of students availability at the school should be assumed.

The above need to be considered and body weight ratio (student/adult) applied.

The volume of biogas production per person was reported at 0.02-0.028 m^3/person/day in an experiment in Uganda (E.Menya and Y. Alokore, 2013). By applying the average value of this, the amount of biogas production from human waste is estimated using the following formula:

$$V_h = 0.024N_h \times O \times D \times R$$

Where, V_h: Volume of biogas production from human waste (m^3/year)
N_h: Number of persons utilizing toilets connected to the digester at the facility
O: Body weight ratio, average weight of persons/average weight of adults
D: Number of regular days (= 365 – number of long holidays))
R: Toilet usage ratio (percentage of toilet use connected to the digester)

The value O depends on the average age of students. For high schools, 0.8 was applied. The value D was estimated from school holidays when students and teachers are absent. In this study, 0.75 was applied. The value R was estimated by assumption of how often the toilets connected to a digester are used, when different types of toilets not connected to a digester are installed at a facility. This value was determined through interviews about the situation at each school (0.3-1.0).

Example-3: Average Biogas production per day by 1000 students:

1000 students x 0.024 m^3/person/day x 0.8 x (365-92) x 0.75 x= 3942 m^3/year

4.4 Calculation of Fuel and Fuelwood Saving

To assess the amount of fuelwood or other type of fuel to be saved by production of biogas for cooking, it is necessary to calculate the amount of energy saved by biogas. Energy from fuelwood or other fuels is calculated using the following formula.

Energy = Heat Value of Fuel x Fuel Amount x Efficiency

∴ Fuel Amount = Energy / Calorific Value of Fuel / Efficiency

For the unit of energy, Mega-joule (MJ) is generally used. Heat value is specific to each fuel type, as shown in the table below.

Table 4.4.1 Heat Value of Fuels

Fuel Type	Value	Unit
LPG	45-51	MJ/kg
LPG	26	MJ/L
Natural gas	37.3	MJ/kg
Kerosene	36.7	MJ/L
Diesel oil	37.7	MJ/L
Coal	22-26	MJ/kg
Biogas	20-30	MJ/m3
Firewood*	10-20	MJ/kg

* Depending on type and moisture content

Heat value of fuelwood varies significantly depending on the type of fuelwood and its moisture component. When a higher quantity of water is contained in fuelwood, e.g. fresh wood, heat is utilized to vaporize internal water and thus reducing the heat value of the fuelwood overall. If fuelwood is sufficiently dried, its moisture content is low and heat value will therefore be high.

The table below shows various types of fuelwood, and their corresponding moisture content and heat value.

Table 4.4.2 Moisture Percentage and Heat Value of Fuelwood

Fuelwood Type	Moisture%	Value	Unit
Green wood	50%	9.5	MJ/kg
Seasoned wood	20%	15.5	MJ/kg
Dry sawdust	13%	16.2	MJ/kg
Wood pellets	10%	16.8	MJ/kg
Dry wood (non-resinous)	0%	19	MJ/kg
Dry wood (resinous)	0%	22.5	MJ/kg
Dry steamwood	0%	19.1	MJ/kg
Dry bark	0%	19.6	MJ/kg
Dry branches	0%	20.1	MJ/kg
Dry needles	0%	20.4	MJ/kg

Source: Sustainable Forestry for Bio-based Products, Ashton S, 2007

The efficiencies of stoves vary depending on the type of stove. Generally, efficiency values are as summarized in the following table.

Table 4.4.3 Efficiency of Stoves

Stove Type	Efficiency
Wood stove	10-25%
Three stone stove	8%
Single and two pot mud stove	13%
Charcoal stove	20-35%
Biogas stove	45-55%
LPG stove	60%
Electric stove	70-85%

Source: Efficiency Measurement of Biogas, Kerosene, and LPG Stoves, Center for Energy Studies, 2001, Nepal and other website materials collected by JET

From the above data, heat value of produced biogas and amount of fuel saving can be calculated. The following is an example to calculate amount of fuelwood that can be saved from production of 10 m^3/day of biogas. This amount of biogas is almost equal to that calculated in Chapters 4.2.2 and 4.2.3.

Example: Fuelwood saving from production of 10m^3/day of biogas

Biogas: 10 m^3/day x 20 MJ/m^3 x 0.45 = 90 MJ/day

Fuelwood saving: 90 MJ/day / (15.5 MJ/kg) / 10% = 58 kg/day

(efficiency of fuelwood stove is 10% in above calculation)

This means that production of 10 m^3/day of biogas (from 15 cows or 1000 students) can save 58 kg/day (21 tons/year) of fuelwood.

4.5 Calculation of Electricity Saving

If biogas replaces grid electricity, it is necessary to consider the possible saved amount of electric energy in kWh. If biogas replaces independent diesel generation, it is necessary to estimate possible saved amount of diesel oil.

To calculate possible amount of electricity generated from produced biogas, generator efficiency is required. For this, manufacturer's specification values for the biogas generator and actual operation experience can be applied. The following tables summarize the efficiencies of generators obtained from various manufacturers' specifications. However, it is better to obtain data from existing facilities and apply the value.

Table 4.5.1 Parameters for Calculation of Electricity Saving

Type of Generation and Item	Value	Unit
Diesel oil generation efficiency	3.0-3.7	kWh/L
Biogas generation efficiency	1.0-2.0	kWh/m^3

Example: Electricity Saving from production of 10 m^3/day of biogas

Electricity saving: 10m^3/day x 1.0 kWh/m^3 = 10 kWh/day

Diesel oil saving: 10 kWh/day / 3.0 kWh/L = 3.33 L /day

4.6 Demand Assessment

Assessing the demand of the facility is required in biogas system planning. Generally, the amount of feedstock available is not sufficient to meet the entire energy demand of a facility. It is therefore necessary to confirm the priority of energy saving for users, assess economic efficiency, and prioritize the type of energy to be saved by biogas system. The followings are the possible demand for energy saving:

- Electricity by diesel generation
- Electricity from grid
- Fuelwood
- Charcoal or coal
- LPG

It is necessary to collect information on the unit price of the above fuels in order to calculate financial and economic benefits.

To confirm demand, the following table can be used to collect information through a site survey.

Table 4.6.1 Information Items for Demand Assessment

Current energy usage	Unit	Amount, remarks
Electricity usage	kWh/mon	
Electricity tariff payment record (from bills, average in several months)	Ksh/mon	
Current use of electric/heat appliance (type, hours) Light, PC, mobile charge, TV, radio, cooking heater, other		
Diesel generator and oil for generation, if any, cost	L/day, L/mon, Ksh/L	
Type of fuel for cooking (Fuel wood, LPG, etc)		
Current usage of fuel wood, cost	kg/day, t/mon, Ksh/ton	
Current usage of LPG, cost	cylinder(kg)/mon Ksh/Cylinder	
Current usage of other fuel	unit, amount, Ksh/unit	
Source of water supply (pump, etc.)		
Type of lighting		
Priority usage of gas (electricity, fuel, etc)		

To determine the generation system, electricity demand needs to be specified and may include lighting or water supply. Generally, biogas generators can meet demand of 5-20 kW, based on the available amount of feedstock in typical facilities. The following data need to be collected at site.

- Maximum output of pump for water supply (kW or kVA)
- Number of electric lighting appliances

See Chapter 5.6 for the selection of biogas generator capacity.

4.7 Determination of System Layout

In the site survey, a sketch of the facility is required to prepare system layout.

The location of digester should consider the following aspects:

- The site should be in a slightly higher elevation than the surrounding. This helps in avoiding water logging.
- Elevation arrangement for gravitational flow of feedstock and effluent should be considered to avoid manual transportation
  - Input location of digester should be lower than cow shed
  - Garden for effluent should be lower than outlet of digester
- Possibility of contamination of underground water should be considered carefully and the

facility should not be located near water supply systems such as wells.

- Location of digester should be close to cow shed, garden, kitchen and generator, but not close to classrooms, houses, etc. due to possible odor.
- Gas pipe line length should be kept as short as possible. A longer pipe increases the risk of gas leakage because of the increased number of joints and makes cost higher.
- In order to keep higher temperature, location of digester should be sunny. (Optimal temperature is 35 degree-C).
- The digester location should have sufficient distance from trees to avoid damage of digester from roots.
- The edge of the foundation of the plant should be at least two meters away from any other structures to avoid risk of damage during construction;
- The plant should be at least 10 meters away from groundwater wells or surface water bodies to protect water from pollution.
- As necessary, topological survey at the level of 1/500-1/2000 scale may conducted as well.

The following illustration explains material flow by gravity for cow shed, digester and garden.

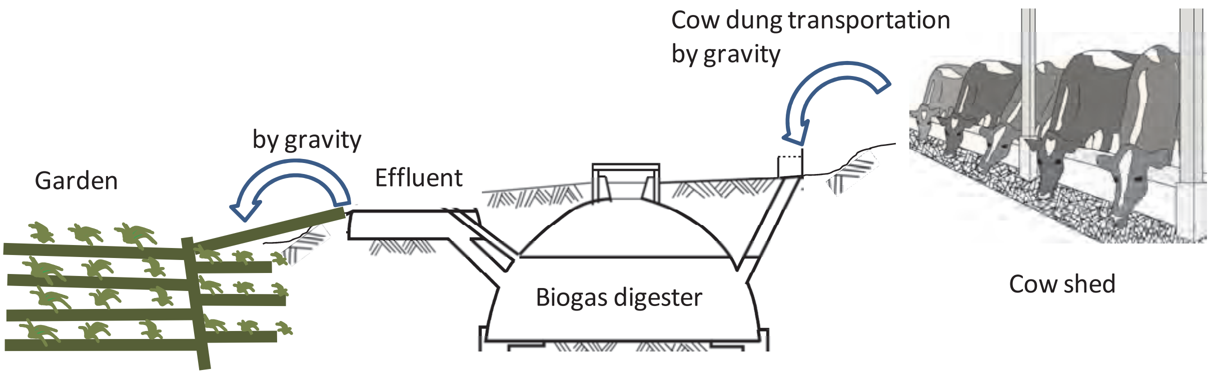


Figure 4.7.1 Consideration of Elevation for Material Flow to and from Cow Dung Digester

As for a digester connected to toilets, it is necessary to check existing sewer lines in the survey. Pipes to and from the existing septic tank must be connected with due consideration of gravitational flow. Accordingly, it is better to install the biogas digester between toilets and septic tank, just upstream of the septic tank.

The following figure illustrates the flow of materials for a biogas digester connected to toilets.

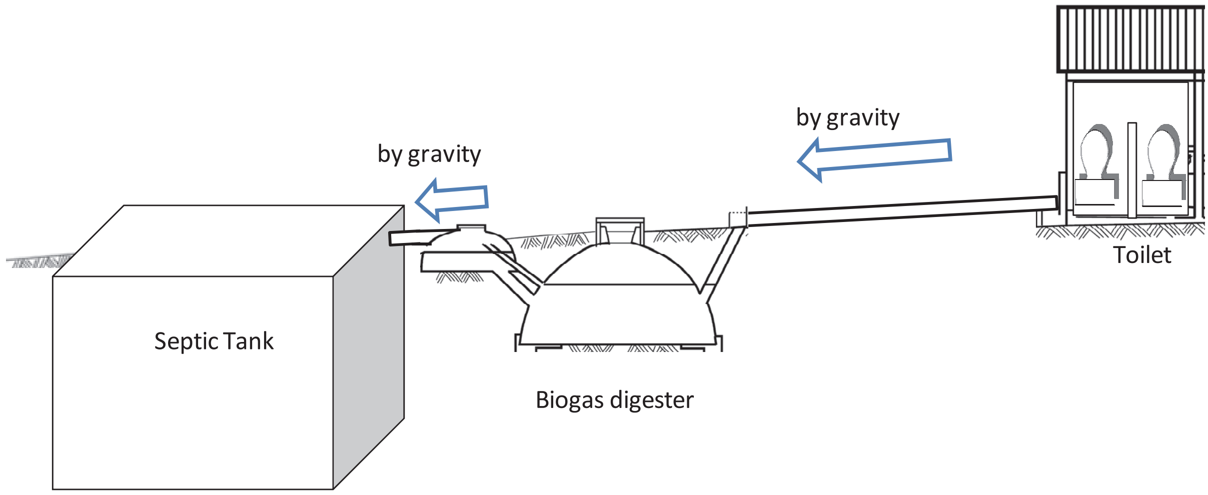


Figure 4.7.2 Consideration of Elevation for Material Flow of Human Waster Digester

Following figure is an example of biogas system layout in facility.

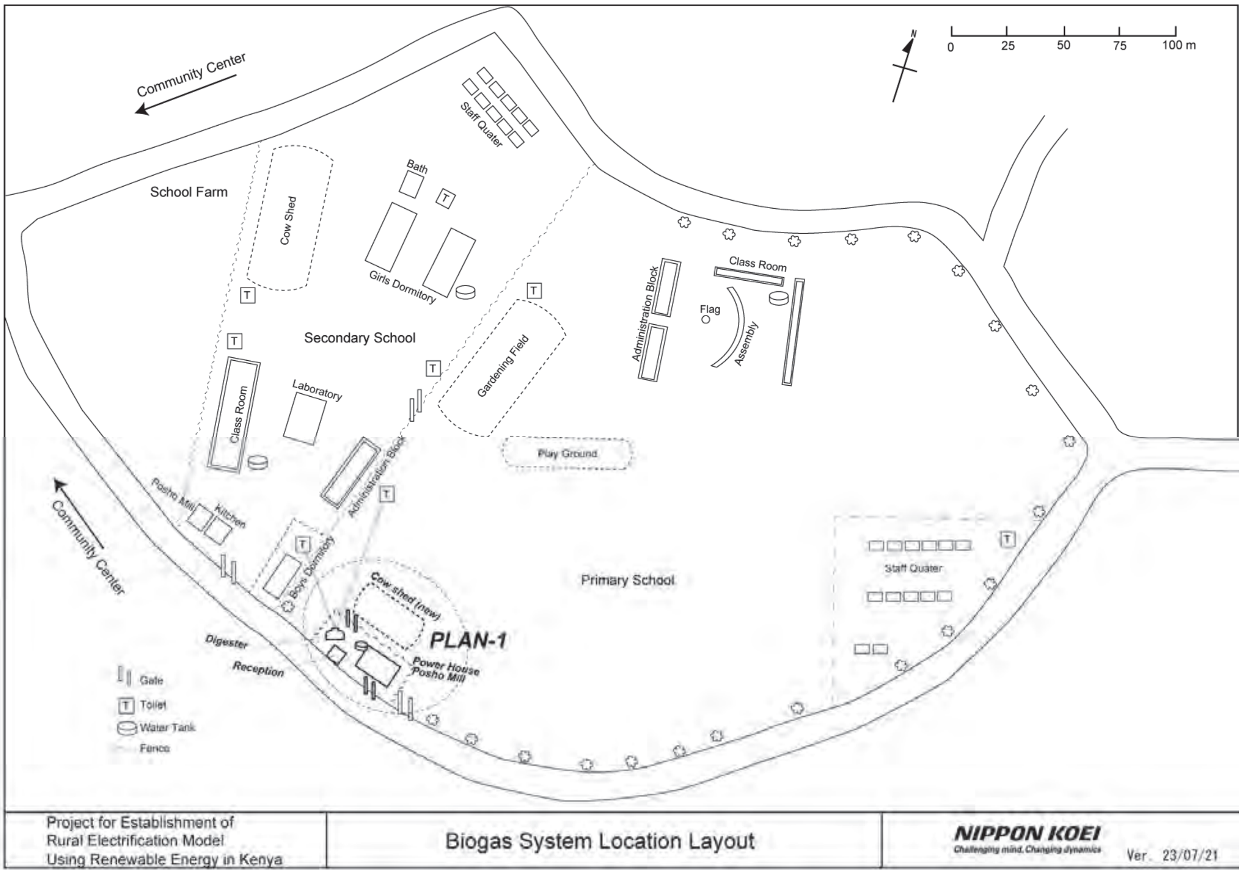


Figure 4.7.3 An Example of Biogas System Location Layout

CHAPTER 5 DESIGN OF BIOGAS SYSTEM

5.1 Biogas Generation System

Biogas generation system consists of i) biogas digester, ii) gas filter, iii) pipe lines, iv) gas holder (gas bag), v) biogas cooking stove, vi) biogas engine and generator, vii) distribution panel and meters, vii) electricity supply unit, and viii) gas flow meters. A typical biogas generation system for off-grid areas is shown in the figure below.

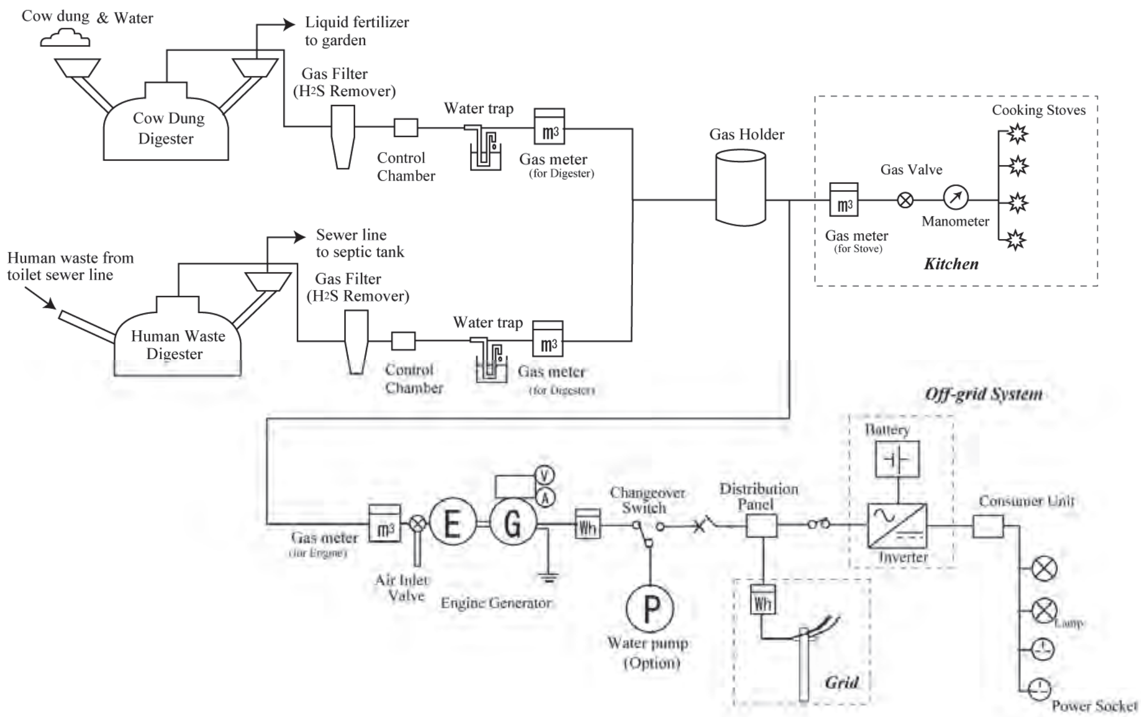


Figure 5.1.1 Conceptual Diagram of Biogas System Flow in Off-grid Area

When the system is installed in grid-connected areas and load is specified -such as water pumping or lighting, battery and inverter are not necessary as highlighted in the above figure. The drawing is attached in Annex-2 Drawing No. G-01 Conceptual Diagram of Biogas System Flow.

5.2 Selection of Biogas Digester

5.2.1 Biogas Digester Type

There are several types of biogas digesters. It needs to select appropriate type of digester according to cost and capacity. The type of digester is as shown in the figure below.

Table 5.2.1 Comparison of Biogas Digester Type

Type of Digester	Advantage	Disadvantage
Plastic bag type 	Inexpensive technology: (USD 130-200) Easy installation without civil works Small digester tank volume, therefore appropriate for few livestock	Very damageable Short lifespan: 4 years max. Relatively few successful installations Not very easy to operate Dismantling and recycling of the unit

Type of Digester	Advantage	Disadvantage
Plastic tank type  Photo from http://trade.indiamart.com/	Easy installation without civil works Quick biogas production start-up after installation Small digester tank volume, therefore appropriate for few livestock	Expensive for volume, Approximately (USD 800-1000) for 1.5-2.0 m^3 Potentially damageable (not underground) Small digester volume available, hence low biogas production Few existing installations, little feedback Dismantling and recycling of the unit
Floating drum type  Photo from http://www.enea-consulting.com/	Provides constant gas pressure at Outlet Visual indication (floating gasholder level above the pit) of the amount of available gas is possible	Very expensive compared to fixed dome digesters Steel drum (gasholder) is subject to corrosion Shorter lifespan than fixed dome technology
Fixed dome type 	Long lifespan: more than 20 years Not damageable (underground) Many references for other fixed dome technologies (e.g. 2,700 units in Rwanda, 8,000 units in Kenya and 250,000 units in Nepal) Easy to operate	Expensive technology USD 800-1500 for household units Potentially long durations before the start-up of the biogas production Maximum size is up to 100m^3
Covered Rangoon Type  Photo from http://www.biodome-asia.com/	Applicable for large installation of 1000 m^3 scale. Large scale application for several hundreds kW generation is possible.	Construction cost is high. Membrane life is short and it needs replacement.

From the above table, it is considered that the fixed dome type of biogas digester is the most suitable for facility installation and applied in this Guideline with the following reasons:

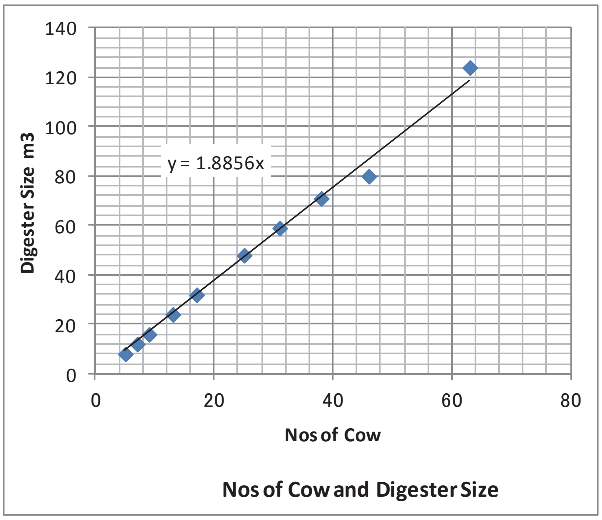
- Population of school or public facilities of biogas project target in Kenya is 1,000-2,000 at the maximum. In this scale of feedstock production from the facilities, fixed dome type can sufficiently cover the amount of gas production both from human waste and cow/pig/poultry dung . If one unit of digester is not sufficient, several units of digesters can also be installed.
- Fixed dome type has the life more than 30 years if it is properly constructed. Meanwhile, Covered Rangoon Type requires membrane replacement every 5-10 years, which imposes large O&M cost on users. This is not favorable for public facilities who do not have business income to support O&M.

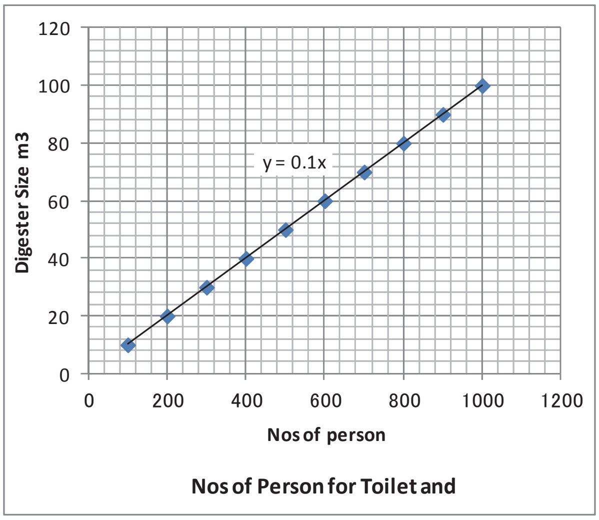
5.2.2 Determination of Biogas Digester Size

For the determination of biogas digester size, the following experimental value from past projects in other countries can be referred.

$$V_{dc} = 1.89 \times N_c \ , \quad V_{dh} = 0.1 \times N_h$$

Where, V_{dc}: Volume of cow dung digester (m^3)
V_{dh}: Volume of human waste digester (m^3)





The above graph is prepared by JET with following reference materials:
Source (Cow dung): Biogas Construction Manual for Contractors, GIZ
Source (Person for Toilet): Ensuring Appropriateness of Biogas Sanitation Systems for Prisons - Analysis from Rwanda, Nepal and the Philippines

Figure 5.2.1 Biogas Digester Size and Number of Cows and Number of People

It is recommended to select one size larger than the possible size identified in the above estimation.

(1) Details for cow dung digester estimation

As for cow dung, the above figure was prepared based on a table in Biogas Construction Manual of GIZ.

Table 5.2.2 Digester Size by Daily Cow Dung Production

Digestor Size m^3	Dung/day kg	Nos of cow*	Produced gas m^3
8	100	5	3
12	150	7	4.5
16	200	9	6
24	300	13	9
32	400	17	12
48	600	25	18
59	740	31	22
71	900	38	28
80	1100	46	34
124	1500	63	46

* Number of cow is assumed that a cow produces 20-24 kg/day.
This amount will vary according to status of cows.

The digester size is generally determined based on the following formula.

Digester Size (m^3) = RT (Retention Time, days) x [Feedstock Input (m^3) + water (m^3)]

Water quantity equal to the quantity of cow dung should be supplied to the digester. Urine from the cows is assumed to contribute to the supply of water required. Cow dung can therefore be considered to contain water in the form of urine (reportedly, in average, 10.8 kg/day per cow in dry areas, and 21.9 kg/day per lactating cow[1]).

The retention time of cow dung is generally reported at 30-50 days[2]. Based on the above formula, the digester size corresponding to various retention times is summarized in the following table.

Table 5.2.3 Digester Size Corresponding to Retention Time of Cow Dung

GIZ Table				Digester size m^3 by RT	
Digestor Size m^3	Dung/day kg	Produced gas m^3	Nos of cow*	RT=40 d	RT=50 d
8	100	3	5	8.0	10.0
12	150	4.5	7	12.0	15.0
16	200	6	9	16.0	20.0
24	300	9	13	24.0	30.0
32	400	12	17	32.0	40.0
48	600	18	25	48.0	60.0
59	740	22	31	59.2	74.0
71	900	28	38	72.0	90.0
80	1100	34	46	88.0	110.0
124	1500	46	63	120.0	150.0

* Number of cow is assumed that a cow produces 20-24 kg/day.

As shown in the above table, digester size derived from the GIZ table is almost equal to that calculated based on the assumption that retention time is 40 days. Retention time largely depends on temperature in the digester. Higher temperatures require shorter retention time and vice versa. If the average temperature is below 30 degrees-C, it is recommended to design a larger digester size with an additional 10-20% volume.

Maximum digester size is considered to be 100 m^3 for fixed dome type digester considering structural strength. If a larger digester capacity is required, it is recommended to install several units of digesters, all within 100m^3 maximum digester volume.

(2) Human waste digester estimation

As for digesters connected to human waste supply, rough estimation of volume is calculated as 0.1 m^3 per adult person. This is estimated with the assumptions that diluted human waste with feces, urine, and flush water is 3.3 L/day, and retention time (RT) is 30 days.

5.2.3 Design of Biogas Digester

The design of biogas digester is dependent on the biogas supplier. The following is a sample design, prepared with reference to Biogas Construction Manual, by GIZ, GmbH, and PSDA.

In the GIZ GmbH, and PSDA design, the ring foundation and the conical bottom are applied. The ring foundation carries the structure and the respective earth load on top of it. The bottom slab sustains the sludge inside the digester. As a conical shape for the bottom slab is more stable and provides

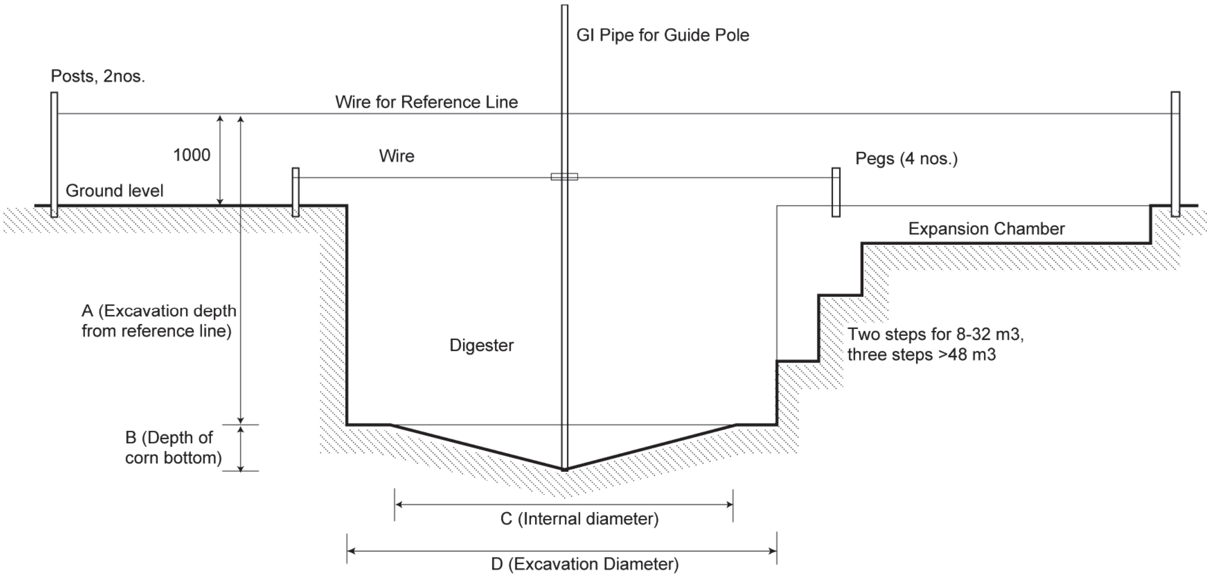
1 Evaluation of Urinary Nitrogen Excretion from Plasma Urea Nitrogen in Dry and Lactating Cows (2008, S. Kume et al. Anim. Sci.Vol. 21, No. 8)

2 "Development of Biogas Processing from Cow dung, Poultry waste, and Water Hyacinth" assumes RT=40 days at 33.4 degrees-C."Comparative study of biogas production from cow dung, cow pea and cassava peeling using 45 litres biogas digester (Ukpai, P. A. and Nnabuchi, M. N2012) experienced RT=30 days, and "Biogas in India" (2010, T. Pydipati) states RT=55 days.

additional volume, it is more preferred than a flat bottom shape.

(1) Plan for excavation

The excavation plan needs to be prepared according to the type and size of biogas digester, as shown in the figure.



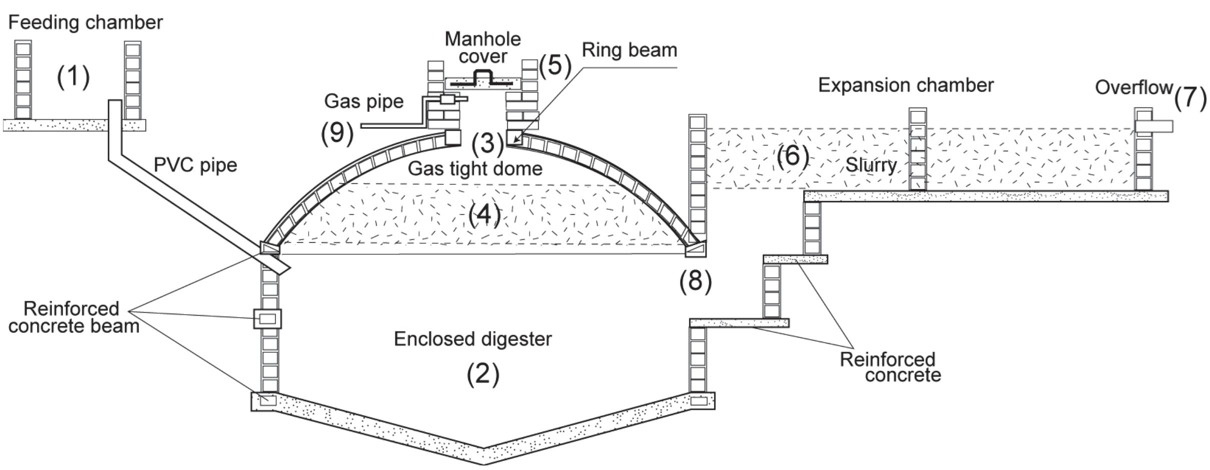
Source: Modified by WG referring to Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.2.2 Plan for Excavation for 60m^3 Biogas Digester

The drawing is attached as Drawing No. G-02 AKUT Type Biogas Digester (8-124 m^3) Excavation Plan in Annex-2.

(2) Biogas Dome, Feeding Chamber, and Expansion Chamber

A typical layout of the biogas dome, feeding chamber, and expansion chamber, and details of the biogas dome are shown in the figure below. For detailed dimensions, refer to AKUT Type Digester, Biogas Construction Manual, prepared by GmbH, and PSDA



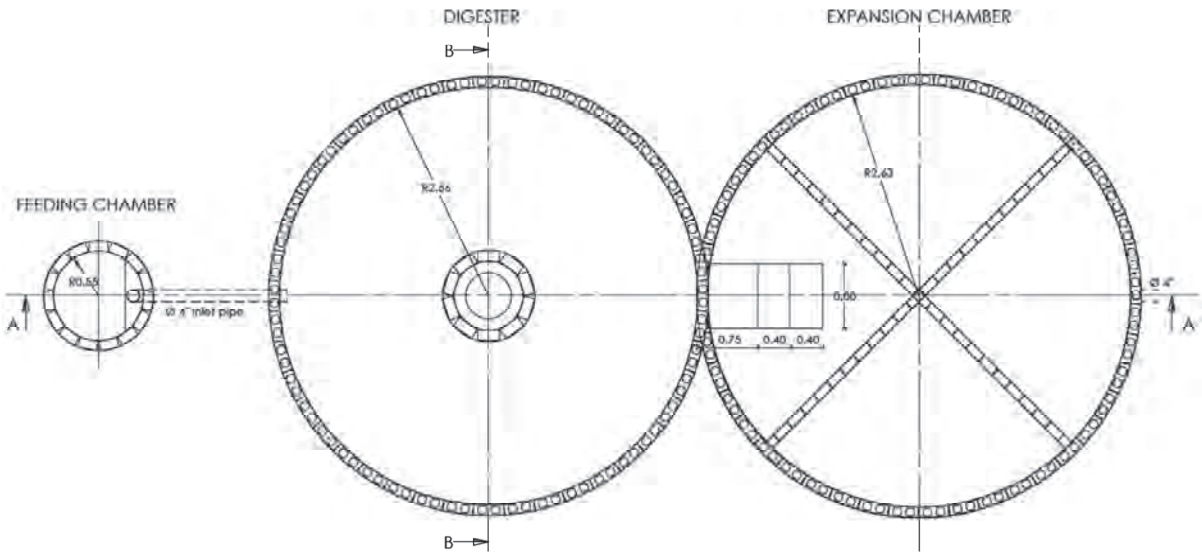
Source: Modified by WG from Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.2.3 Example of Biogas Dome, Feeding Chamber, and Expansion Chamber Layout

The details of biogas digester components vary according to the supplier's design. Feedstock and water are mixed in the Feeding Chamber (1). This is the biogas substrate which is digested at (2). The gas produced by bacteria in the digester is stored in the dome (3). The byproduct of digestion (slurry) flows to the expansion chamber (6). The slurry then flows to a garden or septic tank (7). The gas is collected at (3) and transported through gas pipe (9) to pipeline. When gas increases in the digester, slurry flows out through the "window" (8). When gas is used through the gas pipe (9), slurry flows back into the digester through the "window" (8).

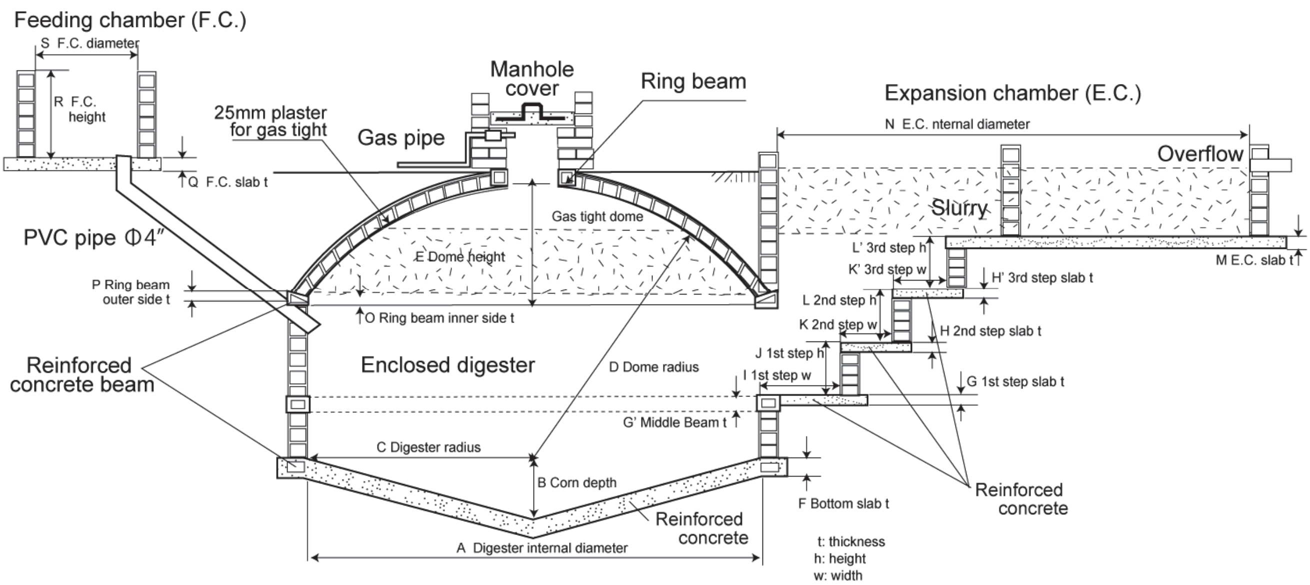
The volume of the expansion chamber (6) is equal to the volume of the gas storage (4). When biogas is produced at (3), gas pressure is created by the difference of the two liquid levels, between the inside lower level of the slurry (10) and the overflow level (7). Thus the maximum gas pressure is determined by the difference between overflow level and upper edge of the "window" (8). The window or vent also functions as an overpressure valve. A manhole (5) is attached for the maintenance of digester and removal of scum or refreshment of substrate.

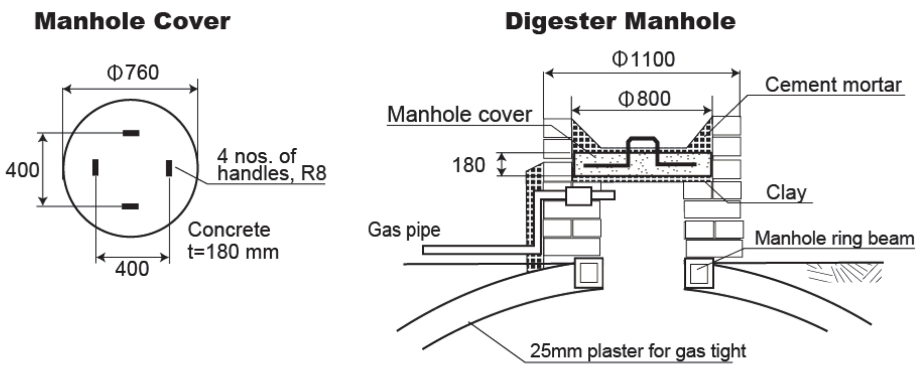
Example of the top view and details of digester is shown in the figures below. Biogas Construction Manual (2011), GIZ, GmbH, and PSDA dimensions.



Source: Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.2.4 Top View of Digester and chambers





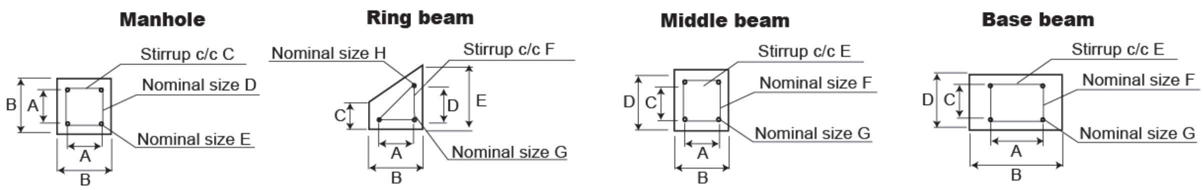
Source: Modified by WG referring to Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.2.5 Detail of Biogas Digester

The drawing is attached for 8-32 m^3 digester as Drawing No. G-03-1 AKUT Type Biogas Digester (8-32 m^3) and 48-124 m^3 digester as Drawing No. G-03-2 AKUT Type Biogas Digester (48-124 m^3)

(3) Reinforcement

For biogas digester strength, enhancement by reinforcement is necessary at the beams. The arrangement of reinforcement is shown in the figure below.



Source: Modified by WG referring to Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.2.6 Arrangement of Reinforcement

The drawing is attached as Drawing No. G-05 Reinforcement Plan and Digester Manhole in Annex-2.

5.3 Design of Pipe

5.3.1 Design of Pipe for Feedstock Flow

Feedstock flow in combination with urine and water is considered to be liquid discharge. Pipe design for feedstock flow needs to be undertaken according to the volume of feedstock and water input.

There are two types of pipes as listed below.

- ✧ PVC (Polyvinyl Chloride) Pipe:
  - Good abrasion resistance but poor resistance to sunlight and physical impact
  - Operation temperature 0-60°C
  - Solvent cement joint
  - Only Class D is acceptable
  - Low cost
- ✧ PPR (Polypropylene) Pipe:
  - Good strength and fatigue resistance
  - Operation temperature -20 to +110 °C

- Fusion welding (requires electricity)
- Suitable for longer distances
- Higher cost than PVC

Pipes and fittings should be of the same brand, to secure connections and ensure unified quality. For the calculation of required pipe diameter, Manning's Formula for hydraulics velocity and discharge in a pipe is applied.

$$Q = V \cdot A$$
$$V = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}}$$

Where, Q: Discharge (m^3/s)

V: Velocity (m/s)

A: Area of flow (m^2)

n: Coarse coefficient = 0.010 (PVC)

R:Hydraulic radius = A/P (m)

P: Wetted perimeter (m)

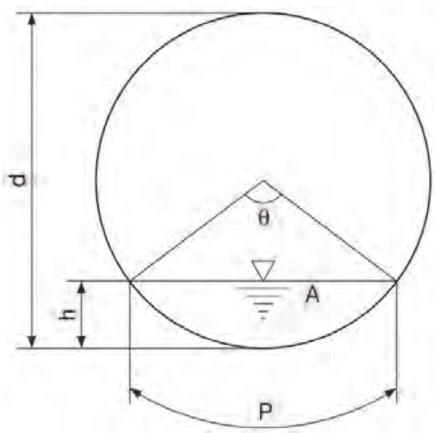
I: Slope

$A = 1/8 \times (\theta - \sin\theta)\, d^2$

θ : central angle (rad.)

d: diameter (m)

$P = 1/2 \times \theta \times d$



If the pipe is full flow, the following can be applied in the above formula.

$$A_{full} = \frac{\pi}{4} d^2$$
$$P_{full} = \pi \cdot d$$
$$R_{full} = \frac{d}{4}$$
$$h_{full} = d$$

For example in PVC 4Φ pipe, flow rate is calculated as follows.

- Φ4" → Diameter 0.1016 m
- Pipe length 1.5 m
- Slope 0.5% (1/200)
- $Q = V \cdot A$
- $V = 1/n \times R^{2/3} \times I^{1/2}$
- n: Coarse coefficient (=0.010)
- R : Hydraulic radius (=D/4=0.1016/4=0.0254)
- I : slope (=0.005)

$\therefore V=1/0.01\times0.0254^{2/3}\times0.005^{1/2} = 2.800$ (m/sec)
$A = \pi \cdot D^2/4 = \pi \cdot 0.04^2/4 = 1.257 \times 10^{-3}$
$Q = 2.800 \times 1.257 \times 10^{-3} \times 10^3 \times 60 = 211$ L/min

Above pipe line is used mainly for human waste digester connected to a septic tank.

A digester of cow dung is connected from cow shed. To enable the transportation of cow dung and cow urine, open ditch is connected with feeding chamber. The open ditch should be stone masonry and enable gravity flow. This aspect needs to be considered in the design.

5.3.2 Design of Pipe for Gas Flow

For the selection of a suitable pipe diameter for biogas flow, PVC or PPR pipes specification sheets can be considered. The design determination can be done with the following tables.

Table 5.3.1 Diameter Design of PVC Pipe

Flow rate (m3/h)	Length (m)			
	20	60	100	150
0.5	0.5"	0.5"	0.5"	1"
1	0.5"	0.5"	0.5"	1"
1.5	0.5"	0.5"	0.5"	1"
2	0.75"	0.75"	0.75"	1"
2.5	1"	1"	1"	1.5"
3	1.5"	1.5"	1.5"	1.5"
4	1.5"	1.5"	1.5"	2.0"

Source: Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Table 5.3.2 Diameter Design of PPR Pipe

Flow rate (m3/h)	Length (m)							
	20	100	150	200	250	300	400	500
0.5	25	25	25	25	25	25	32	32
1	25	25	25	32	32	32	32	40
1.5	25	25	32	32	32	32	40	40
2	32	32	40	40	50	50	50	50
2.5	32	32	40	50	50	50	50	60
3	32	32	50	50	50	50	60	60
4	32	40	50	50	50	60	60	60

Source: Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

For example, if the biogas production is estimated at 10 m^3/day, the flow rate will be 10/24 = 0.42 m^3/h, with a possible variation of 10-20% taken into consideration. Accordingly, flow rate of 1 m^3h/s should be considered to select the optimal diameter of the pipe from the above table, depending on the length of the pipe. The pipe length should be determined according to the facility layout from digester to generator or cooking stove.

5.4 Water Trap

Water trap should be designed in the gas pipe layout. Water is a by-product of biogas, and water vapor will condense in the piping. Automatic water trap (U-shaped siphon) has to be installed. For gas flow in the proper direction, all gas pipes are laid in a slope of 1-2% (1-2 cm per 1m) towards the water traps. This should be clearly mentioned in the specifications to supplier.

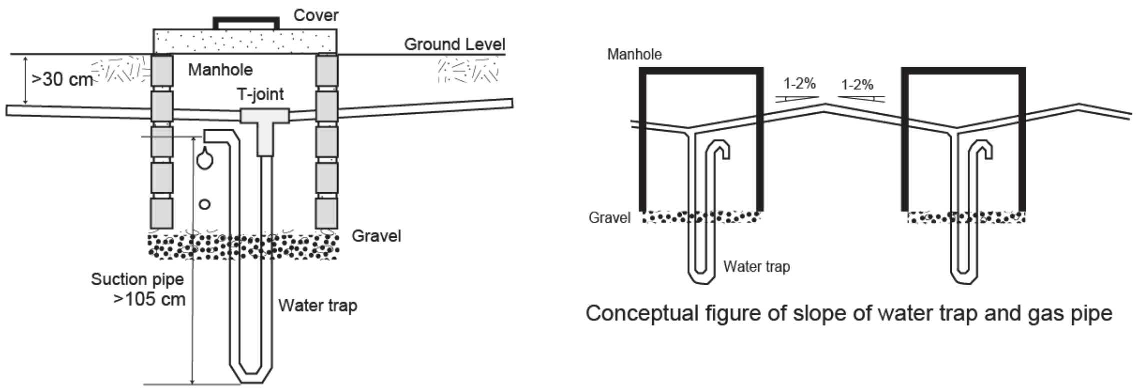


Figure 5.4.1 Shape of Water Trap and its Connections

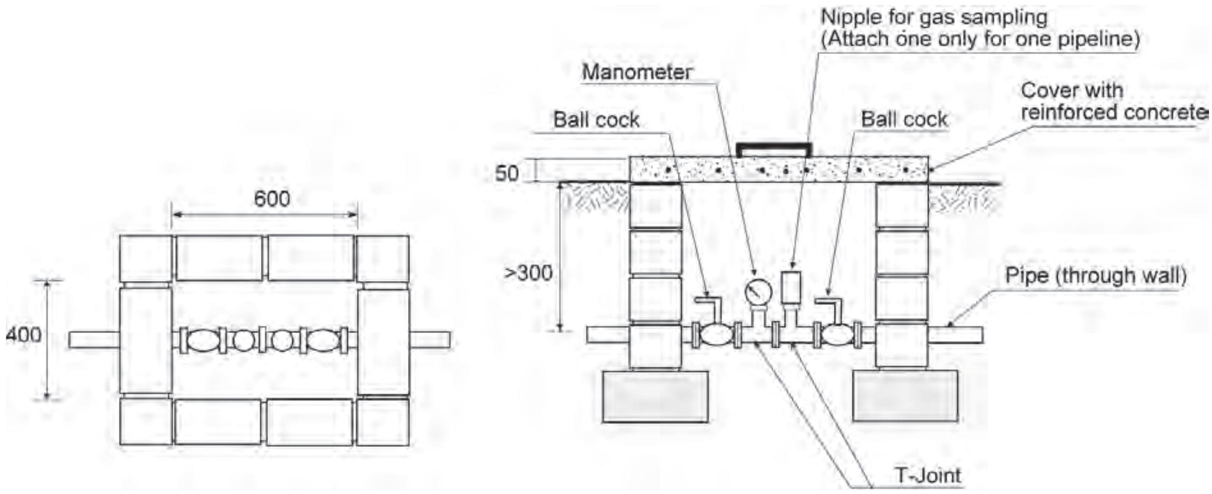
The drawing is attached as Drawing No. G-04 Control Chamber and Water Trap in Annex-2.

5.5 Pressure Test and Sampling Outlet

Conducting pressure tests on the piping system using a manometer is necessary after installation and before backfilling.

The control chamber has to be constructed as a pressure test unit and gas sampling outlet. Close to the digester but outside the dome radius area is preferred. Similar to the water trap, pressure test and gas sampling outlet should be clearly mentioned in the specifications to supplier. Gas sampling is necessary for monitoring, and for research and development purposes. The manometer and nipple for gas sampler should be attached so that gas can be collected from it.

The design of pressure test and sampling outlet, designed by GIZ, GmbH, and PSDA with modification of gas sampling outlet is show in the figure below



Source: Prepared with modification referring to Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 5.5.1 Pressure Test and Sampling Outlet

The drawing is attached as Drawing No. G-04 Control Chamber and Water Trap in Annex-2.

5.6 Biogas Engine

5.6.1 Generator Capacity

For the determination of generator capacity, it is necessary to find a suitable load for the biogas generator. Generally, biogas generators cannot cover the entire electric load of the facility. Large power consumption appliances such as printers, copiers, motors, or cooking heaters have large fluctuations of load, and are not recommended for electricity supply from biogas generator. It is better to select stable loads such as water pumps or nighttime lighting, with installation of switching and breakers.

It is necessary to check the load for biogas generator in both kW and kVA.

Load kVA = power (kW) / power factor (cos ϕ)

The power factor of AC electrical power is defined as the ratio of the real power flowing to the load, to the apparent power in the circuit. AC generators have a specific value of power factor. Generally, the power factor for both water pumps and biogas generators is 0.8.

Example:

If water pump output is 10 kW and power factor is 0.8, required generator capacity is:

10 kW/0.8 = 12.5 kVA

The following table is a sample calculation of load and required capacity of generator for nighttime lighting.

Table 5.6.1 Sample Estimation of Generator Capacity

Description	Unit power (W)	Qty	Load (W)	Other
Fluorescent Tube Light (40W)	40	84	3,360	
Fluorescent Tube Light (20W)	20	56	1,120	
Fluorescent Bulb Light	8	56	448	
Mobile phone charge	4.725	10	47	
Total load (W)			4,975	
Safety factor				1.10
Total capacity (W)			5,473	
Generator power factor φ				0.80
Required generator capcity (kVA)				**6.84**

The line that is supplied from biogas generator should be as simple as possible. For example, water pump supply should not be combined with lighting power supply in the same circuit from biogas generator.

5.6.2 Selection of Biogas Engine Generator Type and Specification

A biogas engine generator has specific power output. It is not recommended to synchronize with grid electricity at the level of 10-50 kW, since this scale is less than FIT lower limit of 200 kW in the current regulatory framework in Kenya.

It is necessary to determine a particular load that can be covered by the biogas generator, such as a water pump or lighting. Installation of a switch should also be ensured so that both grid electricity and biogas can supply power. It should be noted that all the electricity used in the facility cannot be covered solely by the biogas engine.

The efficiency (amount of biogas required to produce 1 kWh electric energy) depends on the size and type of the engine, the capacity at which it is used, as well as the calorific value of biogas. For example, the efficiency could be 1.5 m^3/kWh for a small petro-engine generator less than 5 kW, 1.0 m^3/kWh for a 10-20 kW generator, and 0.6 m^3/kWh or less for a large generator more than 50 kW. These are based on optimum load and typical Net Calorific Value (20 MJ/m^3)

In case of a generator covering electricity demand of 10 kWh/day at 20 kW capacity, the biogas consumption would be 10 x 1.0 = 10 m^3 of biogas per day.

It is further noted that the efficiency also depends on the biogas manufacturer's specifications.

Gasoline engines can also be modified to run on biogas, as the basic spark plug combustion technology is the same. Modification requires placing of a biogas/air mixing device between the carburetor and air filter. The rated capacity of the engine is usually derated by 20 to 50%, depending on the engine type and biogas quality.

It is also noted that gas engine generators (gen-sets) are available from about 1 kW and higher capacities However, running such engines at very low loads results in low efficiency and frequent engine failure. The engine generator should be run at stable load suitably matched with the rated capacity of gen-set.

Photo: Petro-engine Generator

Photo: Biogas Generator (20 kVA)

Diesel engines can be run on biogas, to some extent. It should be understood that some amount of diesel (at least 20%, but for proper injector cooling 40% is recommended) is always required for the engine to run. Biogas can therefore replace a large amount of diesel consumption but cannot fully replace it.

In the design, it is essential to identify the specific system components that should be procured. The following is an example of a 20 kW biogas engine generator system.

Table 5.6.2 Example of 20 kW Biogas Engine Generator

Item		Specification Example	Need to specify
Rated power		20 kW	x
Rated frequency		50 Hz	x
Rated voltage		230/400 V (select)	x
Phase		Single/three phase (select)	x
Power factor		0.8	x (minimum value)
Rated current		36 A	
Governing -method		Electrical	x
Protection		IP23 or better	x
Exciting method		Brushless	
Generation efficiency		>80%, 20 MJ/kWh	x
Ignition method		Automatic, electric start	x
Dimension		1500 x 750 x 1200 mm	x (maximum value)
Gas mixer, electronic governor, cooling system, silencer, inlet valve, display panel for output kW, A, V, and rpm shall be provided. Battery for starting shall be supplied and installed. It shall have warranty time more than 1 year and 8000 running hours. Necessary tool kit for maintenance shall be provided.			x
Engine	Type	In-line, 4 strokes, electric control ignition, pre-mixed stoichiometry burn	
	Nos of cylinder	4	
	Total displacement (L)	3.6	
	Rated power (kW)	27	
	Rated speed (r/min)	1500/1800	
	Compression ratio	11.4	
	Starting model	Electrical	
	Fuel	Natural gas or Biogas	x
	Rated-heat consumption (MJ/kWh)	12.8	x (minimum value)

5.6.3 Electrical Design

Generally, biogas systems cannot cover the entire load of the facility. It is therefore necessary to specify the load for generated energy as stated above, and prepare a single line diagram according to the system design.

The following is an example of system concept. In the following figure, generated power from biogas is supplied solely to the water pump.

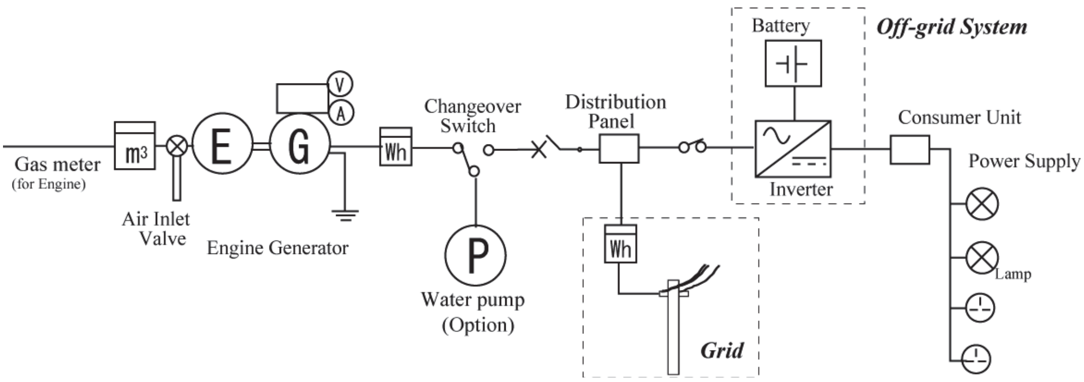


Figure 5.6.1 Example of System Diagram of Biogas Generation

(1) Grid connected system

When the system is installed in a grid connected area, a changeover switch needs to be installed to switch from grid to biogas generator and vice versa. Depending on biogas availability, a specific load such as a water pump is operated using biogas.

If the biogas generated power is provided to lamps and small electric loads, the line and appliances after the consumer unit can be connected to the changeover switch. However, it is essential to provide User guidance to ensure appliances with large loads which cause power fluctuations and excess generator capacity, such as driers or copy machines; are not applied. It is recommended to strictly limit the load to minimal power fluctuations, by supplying applications such as lighting.

It is necessary to consider manual changeover, as it is not realistic to install an automatic changeover switch. Automatic changeover arrangement requires specific design and fabrication with magnetic coil, which makes the investment cost quite high. Automatic changeover is therefore not recommended in small systems.

(2) Off-grid system

When the biogas system is installed in an off-grid area, it provides electricity to two types of loads of users. Depending on the load, electricity can be provided in two methods; three - phase or single - phase. A three - phase system is required for water pumps or large loads, and uses a three - phase generator. The pump capacity should be assessed according to the head, amount of water required and required output.

On the other hand, a single - phase system is used for small power loads such as lighting and mobile phone charging. For this system, a single phase generator, battery, and inverter charger should be installed.

For both systems, the biogas generator can only supply electric power for a limited number of hours, generally 2-3 hours per a day. It is necessary to limit the possible usage hours or install batteries.

5.7 Biogas stoves

5.7.1 Concept of Biogas Stove

Cooking stoves for general application of LPG or other fossil fuel gases cannot be used for application of biogas, as they are. They require modification of flow rate, since calorific value of biogas is different from that of LPG and other fossil fuel gases. Biogas cooking stoves need to be specially adapted. However, many biogas stoves are currently available in the Kenyan market.

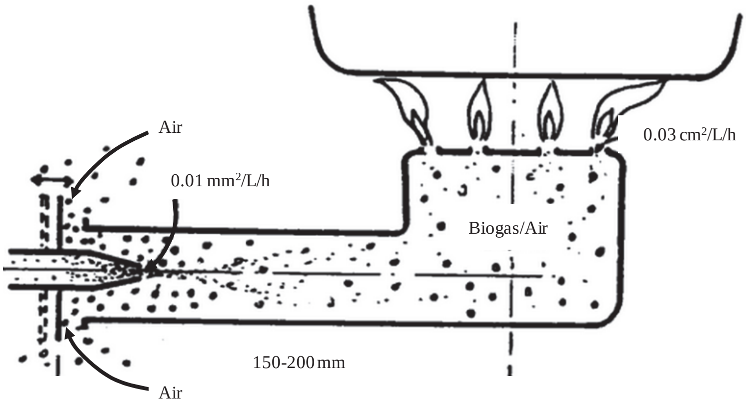
A biogas stove burns the methane component of biogas. The chemical formula for methane combustion is as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

One volume of methane requires two volumes of oxygen, to give one volume of carbon dioxide and two volumes of water (steam). In case the methane component is 60% of biogas and 21% oxygen is provided by ambient air, 1/0.6 = 1.67 m^3 of biogas requires 2/0.21 = 9.52 m^3 volume of air. That is, each 1 volume of biogas requires 9.52/1.67 = 5.7 volumes of air for combustion. Stochiometric air requirement will be 1/(1+5.7) = 14.9% biogas in air.

Biogas will burn over a fairly narrow range of mixtures from 9% to 17% biogas in air. If a flammable gas is burnt with too much fuel content and too little air content, incomplete combustion occurs producing carbon monoxide and soot (carbon particles).

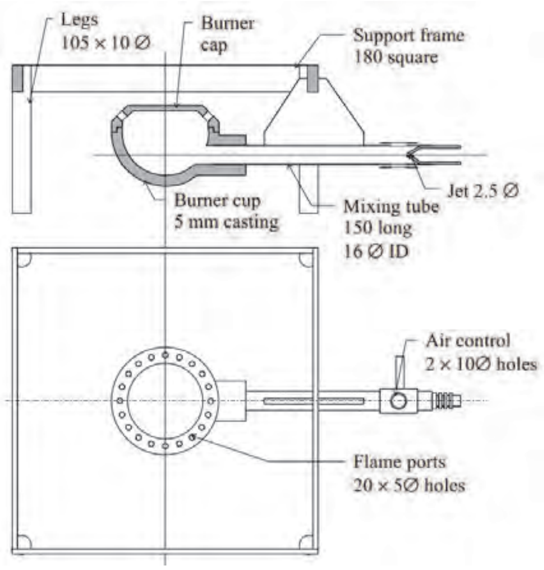
In comparison to other gases such as LPG, biogas needs less air for combustion. LPG requires far more air per volume of gas than biogas. While about 5.7 m^3 of air is required for the complete combustion of 1m^3 of biogas, 30.9 m^3 and 23.8 m^3 of air are required for the complete combustion of 1m^3 of butane and propane respectively. Therefore, conventional gas appliances need larger gas jets when they are used for biogas combustion. Air nozzles should also be different from that of conventional LPG stoves.



Source: http://www.fastonline.org/CD3WD_40/BIOGSHTM/EN/APPLDEV/OPERATION/UTILIZAT.HTML

Figure 5.7.1 Schematic Diagram of Biogas Stove

Biogas is first mixed with a small portion of air for combustion. This is achieved by pressing the gas through a small orifice and creating a gas jet. This gas jet creates a slight under pressure when directed into a tube, causing flow of air into the inlet.



Source: Biogas Stove Design, David Fulford, 1996 Photo was taken by JICA Expert Team

Figure 5.7.2 Drawing of Biogas Stove

A manometer that indicates biogas pressure should be attached for biogas stove to let the user know the amount of available biogas. Analogue pressure indicator is available. Otherwise, a simple manometer consists of transparent hose with a brass spigot at biogas inlet side and a metal clip at the end of hose. The conceptual figure of a manometer is shown in the figure below.

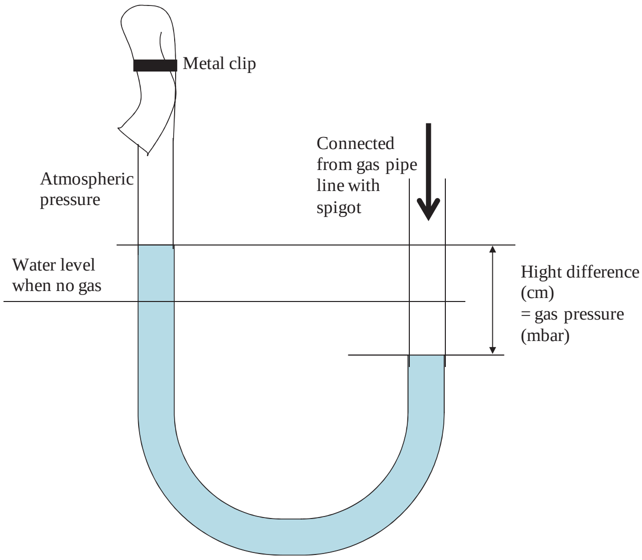


Figure 5.7.3 Concept of Manometer

5.7.2 Biogas Stove Output Power

There are various sizes of cooking stoves, ranging from small household sizes of 1-2 kW power (approx. 0.5 m^3/h) to stoves for institutional use with a power of over 10 kW (more than 4 m^3/h).

When selecting a stove, it is important to determine the required power. The stove output power (P in kW) is shown in the following experimental formula for reference:

$$P = 5.2 \times V / t$$

Where, P : power (kW)

V: volume (Liter),

t : time (min)

If it takes 10 minutes to boil 3 liters of water, the power requirement will be 5.2 x 3 /10 = 1.56 kW.

The gas flow rate of the stove is calculated from the required power using the following experimental calculation:

$$Q = 0.45 \times P$$

Where, Q: gas flow (m^3/h)

If the required stove power is 1.56 kW, the stove should have a gas flow of 0.7 m^3/h.

5.7.3 Biogas Stove Pressure

The stove pressure needs to be close to the biogas pressure. The stove will function at a lower power if the gas is supplied at a lower pressure. The stove output is calculated from; the rated stove power, the rated biogas pressure and the actual biogas pressure using with the following equation:

$$P_{actual} = P_{stove} \times \sqrt{\frac{p_2}{p_1}}$$

Where, P_{actual}: Actual stove output

P_{stove}: Rated stove power

p_1: Rated biogas pressure

p_2: Actual biogas pressure

When the rated power of the stove is 1.56 kW at a biogas pressure of 20 mbar, and the actual biogas pressure is 15 mbar, the actual stove power will be 1.35 kW.

CHAPTER 6 COST ESTIMATION

6.1 Outline of Cost Estimation

Cost estimation is conducted for the purpose of preliminary financial and economic evaluation to assess the project feasibility. Estimated prices are used for budgeting and as reference prices for tender evaluation. Cost components consist of the following items:

Initial investment cost:

- Equipment,
- Material,
- Construction,
- Labor,
- Design,
- Transportation,
- Administration,
- Testing and commissioning,
- User training,
- Documentation,
- Annual cost,
- Operation and maintenance, and
- Overhaul or renewal, etc.

There are various methods for cost estimation based on required accuracy and scale.

(1) Pre-F/S level

This is used for rough estimation. Past tender prices of similar projects are referred for each component. Items that are not included in past projects require cost survey in the market. The estimated price needs to reflect inflation rate considering referred project year and value at present.

The estimation is based on rough assumptions of quantity, especially in civil works. The quantity of excavation, cement, concrete works, buildings, etc, needs to be determined with more detailed layout and design in the next stage.

In the case of small scale projects where the funder considers the rough estimates sufficient to determine financing arrangement, the cost estimation will suffice. For biogas projects with a production level of 5-50 m^3/day, pre-F/S level would be sufficient.

(2) F/S level

If the project is not small scale and requires large initial investment, detailed cost estimation is required. It is necessary to conduct design to quantify each item. Unit cost information needs to be studied using annual construction material cost book and/or obtaining quotations from suppliers. For unit cost of construction material, “Current Construction Cost Handbook”, issued by Ministry of Public Works can be referred.

6.2 Example of Cost Estimation

For Pre-F/S level cost estimation, tender price or contract price for past projects are referred.

For example, past REA projects can be referred for the base cost of biogas system component.

It needs to obtain actual tender price of recent year for cost estimation.
The base cost in the above table is the one for past year. Inflation rate should be applied and price at

the time of procurement need to be calculated with compounded interest.

It is necessary to obtain actual tender prices of recent projects and years for cost estimation.

If the base cost is from previous years, inflation rate should be applied and price at the time of procurement calculated with compounded interest.

The table below is an example of cost estimation items for a biogas system.

Table 6.2.1 Example of Cost Estimation

Item	xxx School		
	Qty	**unit**	**KSh**
Biogas Digester for Toilet	60	m3	xxx
Biogas Digeter for Cow Shed	32	m3	xxx
Excavation and civil works	1	lot	xxx
Additional toilet facility with septic tank			xxx
Gas holding steel tank and connection valve	2	nos	xxx
Bigoas flow meter	2	nos	xxx
PVC gas bag	1	nos	xxx
Biogas generator	20	kVA	xxx
Energy meter	1	nos	xxx
Distribution board, switch gear	1	nos	xxx
Biogas filter and solenoid valve	1	nos	xxx
Cable work	1	lot	xxx
Pipe work	1	lot	xxx
Fence and safety arrangement	1	lot	xxx
Subtotal			xxx
Detailed design and drawing	1	lot	xxx
Testing, commissioning, training	1	lot	xxx
Total Cost			xxx
Total Cost adjusted with Inflation 2010/13	4.91%	Ksh	xxx
Annual financial benefit		Ksh	xxx
Recovery year		yr	xxx
Remarks			

CHAPTER 7 FINANCIAL AND ECONOMIC EVALUATION

7.1 Financial Evaluation and Economic Evaluation

It is important to understand the difference between economic evaluation and financial evaluation. Both are evaluated using internal rate of return (IRR), however, the components counted as benefit are different.

A discount rate needs to be set for both economic and financial evaluation. Discount rate is defined as the annual rate for conversion of the future value of cost and benefit to their present value, in cash analysis.

The difference between financial evaluation and economic evaluation is as follows:

(1) Financial Evaluation:

Financial evaluation is evaluated by monetary cash flow. General objectives of financial evaluation are as follows:

- To assess future profit of the project for investors
- To avoid risk of dead loan for the borrower (project owner)

Financial evaluation is conducted by business managers, planners, banks, investors, etc to assess financial feasibility.

Meanwhile, the following are the objectives for a development project:

- To confirm financial feasibility for O&M
- To assess if the project is “worth while” to implement

For discount rate setting, Opportunity Cost of Capital (OCC) is the key index in the financial evaluation. The interest rate of Treasury bills (long-time government bond) is referred for OCC. It is obtained from national banks or statistics from Ministry of Finance, IMF, etc.

Central Bank of Kenya publishes outstanding Kenya Treasury Bonds. The rate of treasury bonds may be used as discount rate for financial evaluation. For instance, interest rate of 10% for 20 year bond (FXD1/2011/20) and 12% for 30 year bond (SDB1/2011/30) can be referred when setting discount rate.

(2) Economic Evaluation

Unlike financial evaluation, both tangible and intangible value are counted as benefits in economic evaluation. Tangible benefits are evaluated by kWh, tons of fuelwood, saved cash, and CO_2 reduction. Intangible benefit include benefits in health, education, and environment.

Economic evaluation is conducted to assess the efficiency of resource distribution in a nation’s economy.

Shadow exchange rate (SER) needs to be applied for conversion from financial price, when market price is adjusted by subsidy, custom, and import quota. Simplified calculation of shadow exchange rate is as following:

$$\mathrm{SER}(\%) = \frac{(\text{total import amount} + \text{total tax revenue from import}) + (\text{total export amount} + \text{total tax revenue from export})}{\text{total import amount} + \text{total export amount}}$$

Decision makers for development projects, such as international development banks, bilateral cooperation agencies such as JICA and GIZ, and policy makers for the government; will use economic evaluation, in addition to financial evaluation, for decision making on project implementation.

SDR (Social Discount Rate) is referred in economic evaluation to judge if projects are feasible.

Generally, 10-12% is the cut-off value to be evaluated to determine feasibility of development projects. For infrastructure projects, the following percentages are used as SDR, for reference.

- UK: 3.5% (from April 2003)
- Germany: 3%
- Japan: 4%
- New Zealand: 10%
- Asian Development Bank: 10-12%

Source: Financial Analysis Basics Course, Foundation for Advanced Studies on International Development

7.2 IRR and Cash Flow

Internal rate of return (IRR) is the measurement index to assess efficiency of capital investment. It is the quantitative evaluation for governmental public expenditure.

IRR means the Discount Rate that makes total net benefit generated during the project period zero. IRR is calculated based on net present value (NPV).

B (Benefit) of the cash flow means income, C (Cost) means expenditure. Cash flow, B-C (benefit minus cost), is referred in IRR calculation.

The percentage "r" of IRR is defined as follows:

Cash Flow = B-C (Benefit – Cost)

$IRR(r) = \Sigma\ [(B\text{-}C)_t\ \ /\ (1+r)^t\ ] = 0$, where t = 1, 2, …, n (year)

$IRR(r) = (B\text{-}C)/(1+r) + (B\text{-}C)_2\ /(1+r)^2 + (B\text{-}C)_3/(1+r)^3 + \ldots.\ (B\text{-}C)_n\ /(1+r)^n$

Where, B: benefit, C: Cost, n: Project Year

$NPV = \Sigma\ [(B\text{-}C)_t\ /\ (1+i)^t\ ]$, where t=1, 2,…,n,

Where, I: discount rate, needs to be determined by evaluator

Financial internal rate of return (FIRR) is calculated in financial analysis. Likewise, economic internal rate of return (EIRR) is calculated in economic analysis.

The followings are remarks pertaining to cost analysis in IRR calculation.

- Cost includes construction and equipment, labor, environment, land, design, operation and maintenance, etc.
- Estimate real resource costs.
- Present value is used. Inflation is not considered.
- Price contingency is not included. Physical contingency should be included.
- Sunk cost (indirect cost before project) is not considered.
- Interest rate and depreciation are not considered.
- Accounts payable and accounts receivable are not considered.

7.3 Financial Benefit for Biogas Project

Financial benefit for FIRR can be calculated with savings on electricity by biogas generator and savings on fuelwood. Calculation of benefit value is conducted in monetary value, KSh in Kenya.

The benefit of biogas system consists of fuel wood savings and electricity savings, and can be calculated based on the amount of fuel wood and/or electricity saved. The benefit of fuel wood saving is calculated using the following formula:

$$S_f = \frac{(V_{cw}+V_{hw})\times C_{gas}}{C_{wood}/E_{stove}}\ , \qquad B_f = S_f\ \times P_{wood}$$

Where,
- S_f: Saved amount of fuel wood by biogas (tons/year)
- V_{cw} and V_{hw} : Volume of biogas V_c and V_h allocated for cooking fuel saving (m^3)
- C_{gas}: Calorific value of produced biogas (MJ/m^3)
- C_{wood}: Calorific value of fuel wood (MJ/ton)
- E_{stove}: Efficiency of cooking stove
- B_f: Benefit of fuel wood saving (KSh)
- P_{wood}: Price of fuel wood (KSh/ton)

Here, calorific value of produced biogas 20 MJ/m^3 (M. Kaltschmittm, 2003) is applied for C_{gas}. The calorific value of fuel wood, C_{wood}, is variable depending on moisture percentage and condition of wood. For dry wood, the value is indicated to be 0.019-0.0225 MJ/ton (Hubbard W., et al., 2007). The value of 0.02 is applied in this study. E_{stove} value depends on the actual cooking stove type that the facility uses, and 10% (N.Shrestha, 2001) can be applied for E_{stove} here. Fuel wood price, P_{wood}, is also variable depending on local conditions. For example, it can be set at KSh. 3,300/ton from local interviews.

The benefit of electricity saving is calculated using the following formula.

$$E_g = G_e \times (V_{ce} + V_{he}), \qquad B_e = T \times E_g$$

Where,
- E_g: Saved amount of electric energy (kWh)
- V_{ce} and V_{he} : Volume of biogas V_c and V_h allocated for electricity saving (m^3)
- G_e: Efficiency of biogas generator (kWh/m^3)
- B_e: Benefit of electricity saving (KSh.)
- T: Power tariff rate (KSh./kWh)

The efficiency of biogas generator, G_e, depends on specification of biogas engine generator. Here, 1.0 kWh/m^3 was applied according to manufactures' specification in past projects. Tariff rate, T, is determined using actual monthly bills of the respective facilities, which is variable (8.7-19.9 KSh/kWh in surveys conducted in 2012-2013).

The following summarizes the method of calculation.

- Electricity saving:
  - ✧ Obtain actual monthly electricity bills of the recipient and calculate average tariff rate (KSh/kWh). (Generally, 18-20 KSh/kWh for grid electricity)
  - ✧ Calculate electricity saving in KSh, as electricity generated (kWh) x tariff rate (KSh/kWh)
  - ✧ If diesel generator is used, estimate the cost of diesel fuel and efficiency of diesel generator in kWh/L depending on recipient.
- Fuelwood saving:
  - ✧ Calculate fuelwood saving amount (ton) x unit fuelwood price (KSh/ton).
  - ✧ Confirm fuelwood purchase price in the area (KSh/ton). (Generally, 3000-4500 KSh/ton)

(1) Financial Benefit from Electricity Saving

The followings are examples of estimating annual benefit for electricity.

- ➢ From electricity bill, consumption is 424 kWh/month and monthly bill is KSh. 7,783.2.
  - ✧ Tariff rate: 7,783.2/424=18.36 KSh/kWh
- ➢ If 15 kWh/day is generated by biogas generator, annual electricity saving is:
  - ✧ 15 kWh x 360 days/year = 5400 kWh/year
  - ✧ 5 days/year are reserved days for maintenance of engine and generator
- ➢ If electricity tariff is 20 KSh/kWh, annual saving is:

- 5400 kWh x 18.36 KSh/kWh = 99,144 KSh/year

- If diesel oil cost for generator is 110 KSh/L and efficiency is 2.4 kWh/L, annual saving for oil is:
  - 5400 kWh x 1/2.4 kWh/L x 110 = 247,500 KSh/year

Generally, diesel oil saving benefit is larger than that of grid electricity for the same amount of electric energy.

(2) Financial Benefit from Fuelwood Saving

The following is an example of benefit estimation for electricity.

- If fuelwood saving amount is 58 kg/day, equivalent to 21.2 ton/year (58 x 365 = 21,170 kg, no maintenance day is required for fuelwood saving) and unit price is 3,300 KSh/ton,
  - 21.2 ton x 3,300 ton/KSh = 69,861 KSh/year

7.4 Economic Benefit for Biogas Project

Both tangible benefits as calculated in financial evaluation and intangible benefits excluded in financial evaluation need to be evaluated in economic evaluation.

To determine economic benefit, it is necessary to quantify indirect values of socioeconomic and environmental benefit. The following table explains the contents of economic benefit which will be derived from the biogas system.

The financial benefit is the same as that estimated in the benefit assessment. The total economic benefit B_{teb} is calculated using the following formula.

For biogas generation system:

$$B_{teb} = B_{ed} + B_{cr}$$

For biogas cooking fuel supply:

$$B_{teb} = B_f + B_{fab} + B_{fco} + B_{fev}$$

For biogas system with generation and cooking fuel supply:

$$B_{teb} = B_{ed} + B_{cr} + B_f + B_{fab} + B_{fco} + B_{fev}$$

The meaning of values is summarized in the following table.

Table 7.4.1 Economic Benefit

B	Type of Economic Benefit	Explanation
B_{teb}	Total economic benefit	Summation of economic benefits to be used for cashflow benefit
B_{ed}	Benefit as electricity saving from diesel oil	When electricity is generated using biogas, the electric energy can be considered to save electricity from grid-connected diesel generation systems, since diesel generation is the most expensive method. The cost of electricity from diesel generation can be considered as economic benefit in place of grid electricity tariff, but not as financial benefit. Diesel Oil Price 110.00 KSh/L and Diesel efficiency 2.40 kWh/L was applied.
B_{cr}	Benefit of carbon reduction by biogas generation	CO_2 emission reduction is expected from biogas generation since it replaces energy from diesel generation. Emission factor of diesel oil can be applied to calculate economic benefit. Emission factor of electricity 0.81805 ton-CO_2/MWh and 1,294 KSh/ton-CO_2 was applied (with exchange rate 86.28 KSh/US$).
B_f	Benefit from fuelwood saving	The benefit is the same as financial benefit of fuel wood saving.
B_{fab}	Fuelwood carbon	Saved fuel wood by biogas can absorb CO_2 in a forest. The carbon

B	Type of Economic Benefit	Explanation
	absorption benefit	credit based on the amount if CO_2 absorbedis considered to be economic benefit.
B_{fco}	Fuelwood carbon off-set benefit	Similar to electricity, saved amount of fuelwood is considered to replace coal conbusted in coal boiler and corresponding amount of CO_2 from the replaced coal. This is considered to be economic benefit of carbon reduction.
B_{fev}	Fuel wood economic value to prevent deforestation	Saving of losses in economic sectors resulting from deforestation is counted as economic benefit. The components of this economic value are: growing of crops and horticulture, fishing, water supply, public administration and defense, deforestation effects on carbon sequestration, and deforestation effects on health, which was quantified at 921,165 KSh/ha (Jackie C, 2012).

To quantify the above economic values, the following parameters need to be set as base conditions. The value is provided as a reference value and needs to be studied to confirm the current conditions.

Base conditions:

Diesel oil price	110.00	KSh/L
Diesel efficiency	2.40	kWh/L
Emission factor of electricity	0.81805	ton-CO_2/MWh
Price of fuelwood	3,300	KSh/ton
Exchange rate	86.28	KSh/US$
Carbon credit	1,294	KSh/ton-CO_2

The methodology for calculating 4 “Fuelwood carbon absorption benefit”, 5 “Fuelwood carbon off-set benefit”, and 6 “Fuelwood economic value” in the above table is illustrated as follows:

(1) Fuelwood carbon absorption benefit

To calculate fuelwood carbon absorption benefit, it is necessary to consider that one ton of fuelwood does not simply directly correspond to one ton of wood in the forest. It is necessary to consider that subordinate parts of wood such as branches and roots, which are not utilized as fuelwood, also contain CO_2. These aspects need to be considered in the evaluation.

For calculation of amount of CO_2 absorption benefit by saving fuelwood, the following formula can be applied.

Carbon Absorption $A = W \times E \times (1+R) \times C\%$

ton-CO_2 reduction = A x 44/12

Where,

W	Weight of saved fuelwood, ton	
E	Coefficient for tree and branch addition:	1.52
R	Ratio of ground/underground portion:	0.26
C%	Carbon component percentage:	0.5

Source: Forestry and Forest Products Research Institute, Japan

Example: CO_2 absorption of 1 ton fuelwood

1 ton x 1.52 x (1+0.26) x 0.5 x 44/12 = 3.51 ton-CO_2

If 10US$/ton-$CO_2$, 1 ton fuelwood has 35.1 US$ carbon credit value

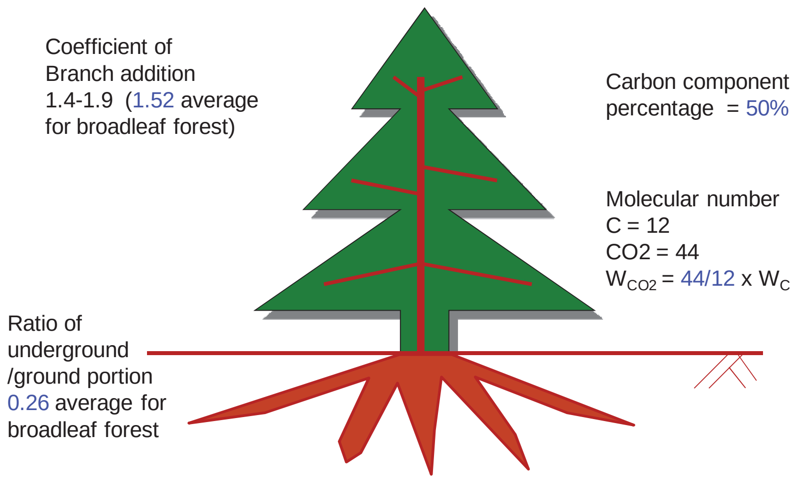


Figure 7.4.1 Concept of Carbon Absorption by Wood

(2) Fuelwood carbon off-set benefit

In economic evaluation method, saved amount of fuelwood is considered to replace coal, and corresponding amount of CO_2 from the replaced coal is considered to be economic benefit of carbon reduction. Fuelwood carbon off-set benefit is calculated as follows:

ton-CO_2 reduction = W x (1-M/100) x H x EF x BE

Where,

W	Weight of saved tree, ton	
M	Moisture content, %:	10
H	Calorific value GJ/ton:	15.5
EF	Emission coefficient of coal, ton-CO2/GJ:	0.09
BE	Boiler efficiency ratio (fuelwood/fossil fuel):	1

Source: Forestry and Forest Products Research Institute, Japan

Example: CO_2 Carbon Off-set from 1 ton fuelwood

1 ton x (1 – 10/100) x 15.5 x 0.09 x 1 = 1.26 ton-CO_2 reduction

(3) Fuelwood economic value

Fuelwood economic value is important to determine the economic benefit. It is necessary to conduct detailed socio economic survey to obtain values. However, for small projects where there is no time and budget to conduct an independent socio-economic survey, the only approach is to refer to existing surveys in areas similar to the project.

The following data is an example of a study of Montane Forests in Kenya.

Fuelwood economic value to prevent deforestation

Amount of carbon storage	190	C-ton/ha
Weight of wood body	198.4	ton/ha
Economic value per area	921,165	KSh/ha
Economic value per ton fuelwood	4,643	KSh/ton

Source: The Role and Contribution of Montane Forests and Related Ecosystem Services to the Kenyan Economy", 2012, UNEP

Values obtained in the above estimation can be used to calculate economic benefit of forest preservation, based on saved amount of fuelwood and electricity by biogas.

7.5 Cost for Financial and Economic Evaluation

The cost items required for financial and economic evaluation are the same. The components are as follows:

- Initial investment
- Annual operation and maintenance cost
  - Administration cost
  - Spare parts cost
  - Overhaul and rehabilitation cost
  - TAX

Initial investment cost is counted as the cost in year zero. Annual operation and maintenance cost is assigned as cost in respective year(s) for whole project duration.

If the project is a government project, tax is not included in the evaluation.

Initial investment cost is the one estimated in the cost estimation, and net present value of above is used in the IRR calculation.

7.6 Example of IRR Calculation

The following items should be prepared before conducting IRR calculation.

- Annual benefit (counted as benefit)
- Project Implementation Cost
- Annual O&M cost
- Tax
- Project year
- Discount rate

Cost and benefit items in respective years need to be prepared and annual cash flow calculated accordingly.

An example for IRR and NPV calculation is shown in the table that follows.

Table 7.6.1 Example of IRR Calculation

Economic Analysis of Nyeri HS

Annual benefit	620,758	KSh
Project investment cost	3,755,264	KSh
Discount rate	10%	
Project year	30	Years
Tax	0%	(Exempted)

Cash Flow (CF)=
Benefit – total Cost

No.	Year	Revenue %	Benefit	Cost					Cash Flow
				Initial Investment	TAX	Rehabilitation	O&M	Total Cost	
			KSh	KSh	KSh	KSh	KSh	KSh	KSh
1	2012	0%	0	3,755,264	0	0	0	3,755,264	-3,755,264
2	2013	100%	620,758		0	0	17,000	17,000	603,758
3	2014	100%	620,758		0	0	17,000	17,000	603,758
4	2015	100%	620,758		0	0	17,000	17,000	603,758
5	2016	100%	620,758		0	0	17,000	17,000	603,758
6	2017	100%	620,758		0	187,763	17,000	204,763	415,995
.									
.									
29	2040	100%	620,758		0	0	17,000	17,000	603,758
30	2041	100%	620,758		0	0	17,000	17,000	603,758
		Total	18,001,991	3,755,264	0	938,816	493,000	5,187,080	12,814,911

=IRR(CF_1+CF_2+…)

NPV(Benefit)= 5,287,510 NPV(Cost)= 3,812,466

EIRR=	15.09%
NPV=	1,475,043
B/C=	1.3869

=NPV(DR, (CF_1+CF_2+…))

=NPV(Benefit)/NPV(Cost)

A detailed example of IRR calculation is shown in Part-III Chapter 2.3 Financial and Economic Evaluation

CHAPTER 8 PROCUREMENT

8.1 Procurement Procedure

Procurement should be conducted according to Public Procurement and Disposal Act 2005 and the Public Procurement and Disposal Regulations 2006 as stipulated by Government of Kenya.

Biogas projects have components of civil works, electrical and mechanical works, and goods. It is therefore necessary to combine applicable descriptions in the tender document.

The procurement method consists of the following:

(1) International open tender

International open tender is applied mainly where there are few or no domestic suppliers who have experience of similar projects, and the tender calls for international suppliers. There is no maximum level of expenditure.

(2) National open tender

National open tender is mainly for tender among national suppliers. When several national suppliers have experiences of similar projects and sufficient ability to implement, this method will be selected.

(3) Restricted tender method

Restricted tender method is the procurement method that relies on the establishment of a list of authorized bidders who will be offered the opportunity to bid for a specific procurement package. The establishment of the list is subject to conditions.

Table 8.1.1 Types of Procurement and Maximum and Minimum Budgets

Type	Goods	Works	Services
International Open Tender	Maximum is the budget allocation		
	No Minimum		
National Open Tender (Threshold Class A)	Maximum is the budget allocation		
	Minimum is Kshs. 6,000,000		Minimum is Kshs. 3,000,000
National Open Tender (Threshold Class B)	Maximum is the budget allocation		
	Minimum is Kshs. 4,000,000		Minimum is Kshs. 2,000,000
National Open Tender (Threshold Class C)	Minimum is Kshs. 3,000,000		Minimum is Kshs. 1,000,000
Class A, B, C is the classification made by procurering entities.			

Source: Prepared from PUBLIC PROCUREMENT AND DISPOSAL GENERAL MANUAL, PPOA

(4) Direct procurement method

Direct procurement does not require the use of competitive bidding. Direct procurement is strictly regulated since it is completely devoid of competition and transparency. It is only applicable in the following cases:

i) When there is only one supplier who can supply the goods, works or services being procured and there is no reasonable alternative or substitute for the goods, works or services, or

ii) Where the goods being produced are urgent and because of the urgency the available methods of procurement are not practical. This type of situations can be regarded as an institutional emergency. In such cases, the circumstances that gave rise to the urgency were not foreseeable and were not the result of dilatory conduct or negligence on the part of the procuring entity.

(5) Request for quotations method.

Procuring entities may request for quotations for goods, works and services which are readily available in the market and whose costs are below the set thresholds in schedule one of the regulations. It is mandatory for the procuring entity to have a pre-qualified suppliers list which is maintained for effective use of the "request for quotations" procurement method.

Procurement for public projects applies Standard Tender Document (STD) of Government of Kenya. The following STD would be applicable for biogas generation projects.

- Standard tender document for procurement of works (buildings and associated civil engineering works
- Standard tender document for procurement of works (electrical and mechanical)
- Standard tender document for procurement of goods
- Standard tender document for turnkey projects

Biogas projects have aspects of civil works, building works, electrical works, and procurement of equipment. Thus, biogas projects are considered to be a combination of the above categories. It is therefore necessary to select the closest category and undertake modifications as required.

The above STDs are available in the Public Procurement Oversight Authority (PPOA) website. PPOA requires that standard tender documents are with minor necessary modifications. Use of any other tender documents developed by a procuring entity requires prior approval of the PPOA

STD generally consists of the following:

- Section I: Invitation to Tender
- Section II: Instructions to Tenderers
- Section III: Conditions of Contract
- Section IV: Appendix to Conditions of Contract
- Section V: Specifications
- Section VI: Drawings
- Section VII: Bills of Quantities
- Section VIII: Standard Forms

The above components are based on STD of buildings and associated civil engineering works. However, the contents of other types of STDs are almost same.

Specific description has to be prepared according to the format. Especially, specifications, drawings, bills of quantities and standard forms have to be prepared according to plan and design. It is also necessary to consider evaluation criteria so that all tenders can be evaluated against the same technical and financial base.

In the specifications, it is necessary to strictly specify quantity and quality requirements, guidelines and standards that the supplier shall follow, including user training requirements, reporting obligations, and testing and commissioning. Further, it is necessary to conduct supervision of suppliers and specify the quality requirements in the specifications to ensure high work quality.

For drawings, it is a requirement to include facility and system layouts, preliminary design of digester, pipe line, single line diagram, and powerhouse layout, and other buildings and facilities for the biogas system.

For bills of quantities, work and equipment quantities need to be specified in a table. The bills of quantity table will be referred to for inspection prior to commissioning in order to assess if the supplier's work has been completed.

8.2 Procedure of Procurement

Generally, the procurement procedure will take more than six months. The tendering process consists of the following tasks:

- Preparation of tender document and specifications

- Request for Expression of Interest and Pre-qualification (when pre-qualification is conducted)
- Invitation to tender or advertisement of procurement
- Preparation of tender
- Bid opening
- Bid evaluation
- Contract negotiation and award

A tendering schedule should be considered and incorporated in the project implementation schedule. A sample procedure and schedule of a general national tender process is shown in the table below.

Table 8.2.1 Example of Procurement Schedule

Work Items	M1				M2				M3				M4				M5				M6				M7				M8				M9			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
Preparation of tender document and specification	■	■	■	■	■	■	■	■																												
(Request for Expression of Interest and Pre-qualification)									■	■	■	■																								
Invitation to tenderer or advertise of procurement													■																							
Preparation of tender														■	■	■	■	■																		
Question and reply about tender															■	■	■																			
Bid opening																			■																	
Bid evaluation																				■	■	■	■													
Contract negotiation award																								■	■											
Implementation and contract administration																										■	■	■	■	■	■	■	■	■	■	■

If funding is provided by an external donor, concurrence processes are required in addition to the above.

8.3 Qualification

The method for qualification is described in detail in Chapter 5 of Public Procurement and Disposal General Manual issued by PPOA.

Eligibility criteria need to be described in the bidding document. For biogas projects, at least three projects with similar technical requirements and budgets should be required of the bidders.

Qualification should include the capability, experience, resources, equipment and facilities to install the biogas system. Qualification criteria may relate to:

i) Technical competencies and resources, including the availability of sufficient manpower, the qualifications and experience of key personnel or managers, available equipment, and manufacturing or construction facilities;

ii) Financial position, including financial soundness, and sufficient turnover or sufficient cash flow;

iii) Experience and satisfactory performance of similar contracts, taking into account relevant factors, including similar or comparable references and litigation record.

For installation of biogas systems, civil and building works capacity is necessary; in addition to biogas installation experience. If the system design includes generation components, electrical work experience and availability of related resources should be examined as well.

A project manager should be assigned, and the bidder required to include a CV showing that the identified person has the necessary capability and experience.

Pre-qualification is the process that the bidders first participate in, bidding to prove their qualification. Pre-qualification criteria is the basis for short-listing bidders for tendering. In applying this method, the time and costs constraints versus the size and estimated value of the procurement requirement should be duly considered. Generally, pre-qualification is conducted for projects with potentially numerous contractors and tight competition in the tender process. For biogas project however, there are potentially few contractors and national open bidding would be applied.

8.4 Construction Supervision

8.4.1 General

It is necessary that the Client provides proper construction supervision at all times, not only during commissioning tests. The construction supervisor needs to have sufficient knowledge and experience of civil, building, and electrical works.

The Contractor shall follow Kenyan Standards (KS) and related international and national standards such as the building code and IEEE. The procuring entity (the Client) should keep and understand related standards. All applied standard shall be currently effective.

The Contractor shall assign a manager in charge of the overall project management, and the proposed manager's CV shall be submitted to the Client for approval.

Work Plan shall be prepared and submitted for approval of the User and the Client. It shall include but not be limited to:

- Detailed work schedule
- Contractor's organization chart and personnel list
- Consolidated drawings of layout of digester, pipe layout, power house, toilet, and other related facility
- Bill of quantity
- Drawings of digester, pipe, power house, generator, and other related facilities that the Contractor will install and/or construct
- Safety plan

8.4.2 Concrete and Other Works

(1) Cement, sand, and aggregate

The cement shall be obtained from an approved manufacturer. The Portland cement shall be delivered to the site in sealed kraft bags which shall be clearly marked with the name of manufacturer, place of production, the type of cement, the year and month produced and the weight contained. The cement must be fresh, without lumps and stored in a dry place. Bags of cement shall never be stacked directly on the floor or against the walls to protect the cement from absorbing moisture before use.

All aggregates and sands shall be free from earth, clay, chalk, lime, peat, loam, soft clay of shale or decomposed stone, vegetable and organic matter and other impurities. The aggregates shall be hard and dense, and spherical or cubical in shape. Provisions shall be made at the site for the separate storage of fine and coarse aggregates, as well as of each size of coarse aggregates, in such a manner as to avoid contamination of the aggregates by foreign materials. If aggregates are dirty, they should be washed with clean water.

Gravel size shall not be too big or too small. Individual gravel diameter shall not be greater than 25% of the thickness of concrete product where it is used. Gravel should not be larger than 2 cm in size.

The quantity of impurities such as mud shall be tested using a bottle test. Fill a bottle or glass with 1/3 sand and 2/3 water and stir vigorously. Leave the bottle in a stationery position to allow the sand to settle. The particles of sand are heavier than those of mud and will settle down quickly. After 60 minutes, measure the layers of mud and sand inside the bottle and compare the height of mud layer against the height of mud and sand layers as a percentage. A maximum of 3% of mud in the sand shall be permissible. If mud and other impurities are more than 3% of the sand, then the sand shall not be used and shall be discarded.

Water for washing aggregates and sands, and mixing and curing of concrete, shall be taken from an approved source and shall be clean and free from deleterious substances including salt, oil, alkali, organic matter and others that may impair strength, appearance and durability of concrete.

If cobble-sized stones are used, individual stone diameter of 7.5 - 30 cm shall be used for masonry work. The stones shall be clean, solid and of good quality; and shall be washed with clean water if they are dirty.

The concrete shall be arranged according to “KS02-594:1986 Specification of Concrete” or other relevant standard(s) approved by the Client. The compressive strength after 28 days shall be more than 20 N/mm^2 otherwise specified. The concrete mixing property shall be submitted and concrete test shall be conducted.

The same clean containers shall be used and the containers shall not be changed during the work to measure the volumes of concrete.

Concrete bases, slabs, beams, and forms and all the reinforcement shall be prepared and shall be ready before the concrete is mixed. All earth bases and forms shall be wet to prevent absorption of water from the concrete, but excess water content in the mixture shall be avoided. All concrete shall be placed within one hour of mixing the cement with water.

Cement shall be prepared according to “KS EAS 19-1:2001 Composition, Specifications and Conformity Criteria for Common Cement” or other relevant standard(s) approved by the Client.

Waterproof cement mortar shall be applied. The mixing and application of a waterproofing agent shall be in accordance with the manufacturer's instructions. The cement mortar shall be applied carefully using steel trowel. The sand to be used in the cement mortar shall be clean, hard, solid and durable and shall not contain harmful amounts of dust, mud, organic matters or other objectionable matter.

Waterproof cement shall not dissolve in water, but shall float when poured into a bucket of water.

(2) Reinforcement

Concrete reinforcement shall be more than the sufficient amount as indicated in the Drawing, which shall be proposed by the Contractor.

Reinforcement steel used in reinforced concrete shall be deformed steel bars, complying with KS573:2008 High Yield Steel Bars for the Reinforcement of Concrete-Specification.

Reinforcement steel shall be stocked on the site, separated into the various sizes in such a manner that the steel does not get contaminated with deleterious matter. The number, size, form and position of all steel reinforcing bars, ties, links, stirrups and other parts of the reinforcement shall be in accordance with the approved drawings and they shall be kept in the correct position and with the required cover without displacement during the process of compacting the concrete in place.

Cutting, bending and splicing of the reinforcement bars shall be carefully carried out in accordance with the shop drawings submitted to the Client for approval.

The bars shall be bent cold in a manner which will not injure the material. Any ties, links or stirrups connecting the bars shall be tauten so that the bars are properly braced and the inside of hooks and bends shall be in actual contract with the bars around which they are intended to fit. Bars shall be bound together with the best black annealed soft-iron wire and the binding shall be twisted tight with pliers. The free ends of binding wire shall be bent inwards.

Before any steel reinforcement is fabricating, any loose mill scale, loose rust and any oil, grease, mud or other deleterious matter shall be removed.

(3) Concrete placement

Before placing any reinforcement bars on the surfaces of earth, gravel, etc., a layer of concrete shall be worked into the cleaned surface to a thickness of 5 cm. Before placing concrete on foundations, the Contractor shall remove from all such surfaces; soil, objectionable coatings, loose or unsound fragments of rock, earth, mud, debris, and stagnant water, and shall keep such surfaces clean and free from stagnant water during concreting operations.

All concrete and mortar shall be placed and compacted within one hour after being mixed; and no partially set material shall be used in the work. The placing of concrete in individual structural members shall be continuous without stopping up to an approved prearranged construction joint or until the member is completed. Concrete placing shall be carried out rapidly to prevent occurrence of cold joints under hot weather conditions.

The Contractor shall take adequate measures to cure the concrete. These shall include covering the concrete with a moist curing mat or other effective means which shall be kept damp continuously and not exposed to sunlight for a minimum period of seven (7) days after casting.

The finished faces of all concrete works shall be sound, solid and free from honeycombing, protuberances and blemishes. No plastering of imperfect concrete faces shall be allowed and any concrete that is defective in any way shall be cut out and replaced to such depth or be made good.

(4) Bricks and blocks

B ricks shall be prepared according to “KS 02-300:1983 Specification for burnt building bricks”, and blocks shall be prepared according to “KS 02-547 Specification for burnt Clay Blocks”, or other relevant standard(s) approved by the Client.

If the Contractor applies precast masonry units, the Contractor shall apply “KS 02-625: 1986 Specification for Precast Masonry Units” or other relevant standard(s) approved by the Client.

The bricks shall be of the best quality of their respective kinds. They shall be hard, square, sound, thoroughly well burnt, true to shape, uniform in size, shape and texture, free from lime and hair cracks, uniform in colour, and clean. The porosity shall in no case exceed 20% by weight, though in the case of engineering bricks not more than 5% will be allowed. Before any order for bricks is made by the Contractor, samples must be submitted to the Client for approval. Manual labour shall be employed in unloading and stacking bricks on delivery. No broken, chipped or cracked bricks shall be brought to the Site.

Bricks shall be built in level courses using bricks of the quality or description specified and to the dimensions shown on the approved drawings. Walls are to be built up in a uniform manner and no one portion raised more than 1 m above another at one time, being racked up and not toothed. All bricks shall be perpendicular, kept strictly plumb and square and the whole properly bonded together so that there are no continuous vertical joints through any two courses of brickwork. No broken bricks will be allowed except where necessary to form proper bonds. The mortar for brickwork shall be, unless otherwise specified, cement and sand mixed in the proportion of 1:3 generally.

Immediately before use, bricks are to be immersed in fresh water and thoroughly wetted. Before continuing partly completed work, the exposed bed shall likewise be wetted. All beds and joints are to be completely filled with cement mortar notwithstanding any local or common custom to the contrary. Where the brickwork is specified to be unpainted, the joints on exposed faces are to be ironed in as the work proceeds and special care is to be taken to give the whole of the joints an even colour. Faces of brickwork due to be plastered shall have joints raked out and left open to form a key for plastering.

Concrete bricks can also be made on-site from cement, sand and ballast chipping if fired bricks are not available or are too expensive. The volume ratio of concrete bricks shall be 1:3:4 for cement: sand: gravel respectively.

Concrete bricks shall be strong (good ratio, mixing, and proper compaction when making) and shall uniformly have a regular shape and size. Concrete bricks shall be cured for at least 7 days before they are used.

The concrete bricks shall have a uniform size of:

- 23 x 11 x 9 cm for smaller - radius digesters (up to 32 m^3), and

- 25 x 12 x 10 cm for larger - radius digesters (above 32 m³).

Bricks with a thickness of less than 9 cm shall not be used.

8.4.3 Biogas Digester

The following are the instructions for construction of a general fixed dome type digester.

When the instructions mention "mixing chamber" and "expansion chamber", the digester utilizes cow dung as feedstock. A toilet connected digester does not have these components and is connected directly with the sewer line.

There are several types in the design of biogas digester. Followings are the general description that the Contractor should follow, referring to AKUT fixed dome biogas digester developed by GIZ. Details may be changed according to specific design of digester.

(1) Finalization of Biogas Location

The finalized location of the digester shall be approved by the User and the Client. The following items shall be considered to determine the finalization location:

- The edge of the foundation of the digester shall be at least two meters away from any other structure to avoid risk of damage during construction.
- The location of digester shall be apart from trees to prevent damage.
- The digester shall be at least 10 meters away from groundwater wells or surface water bodies to prevent water pollution.
- A fixed dome biogas plant shall be constructed as follow: round wall and expansion chamber made of either brick, block or stone, dome made with plain concrete (for small digester less than 10 m3), brick or block, slabs and beam made with reinforced concrete, foundation made with concrete, and feeding chamber made with either stones or bricks.

(2) Marking of Digester Location

After finalization of location, the site layout shall be marked on the ground surface with wooden stakes, rocks, chalk or other materials. The following is an example of a marking method.

1) First, stick a small peg in the ground at the centre spot of the digester.
2) Level the ground and determine the centre line of the digester, feeding chamber, and expansion chamber.
3) Define the reference level. Assume that the ground level is the reference level and indicate this in a drawing. The top of the dome (outer surface) shall be exactly at ground level.
4) Attach a cord to the peg to represent the radius of the digester. Mark the circumference by moving the end of the cord in circular motion.
5) Mark the feeding chamber inlet pipe, feeding chamber, and gas piping.
6) Insert a stick or wooden peg in the leveled ground at the centre of the proposed digester pit. With the help of the stick/peg and cord prepared earlier, mark the circumference of a circle to indicate the area to be dug from the centre point where the central line meets the perimeter line. Draw a tangent to the circle and measure a suitable length.
7) Mark the manhole, ensuring that the inner size.
8) Draw horizontal parallel lines from points on either side of the tangent, which will meet the dome from the centre point where the central line meets the perimeter line. Measure the length of the outlet and the thickness of the wall to define the outer dimension.
9) Check the size diagonally to ensure that the corners are exactly at 90°. Use colored powder to

mark the dimensions.

10) After the site layout is marked, the User should review the selected location again to ensure that the best site has been chosen and the digester will not interfere with user’s activities.

(3) Excavation of Digester

Excavation of the digester pit shall be started after layout is approved. Tools such as crow-bars, picks, spades, shovels and baskets shall be provided by the Contractor. Digging shall be done as per the dimensions fixed during layout. The following conditions shall be maintained:

- If the water table is high and digging to the required depth is difficult, a deeper pit has to be constructed near the digester pit
- Water accumulated in the digester pit has to be drained from the pit through underground pipes or pumping.
- After the required dimension and depth of digging is attained, the work of leveling and ramming the base shall be done. The pit bottom must be leveled and the earth must be untouched.
- Horizontal poles shall be placed at the ground level, crossing each other at 90 degrees at the centre. It shall be ensured that the poles rest on leveled ground.
- For safety, the pit walls shall be vertical and stepped from the ground surface. For each meter in depth excavated, the stepping shall be shifted one meter away from the center of the excavation. If the soil lacks cohesion and the angle of repose needs more slope cutting, scaffolding may be needed.
- Excavated soil shall be placed at least one meter away from the edge of the pit and steps, so that it does not fall back into the pit during works.
- It is not recommended to construct the digester at or below the groundwater table elevation. The earth base of the excavation shall be compacted to attain at least the same degree of consolidation as undisturbed soil in the site. Compaction shall be done using a rammer or compaction tools.

(4) Construction of Digester

The ring foundation and the conical bottom shall be prepared. A conical shape for the bottom slab is more stable and provides additional volume.

1) Foundation

- The digester foundation shall be laid using cobblestones and/or gravel as aggregate then filled with concrete. The foundation shall not be less than 15 cm in thickness and the mixing ratio shall be 1:3:4 for cement: sand: gravel respectively.
- The foundation concrete shall be cured for at least two days.
- The foundation ring where the brick and concrete work settles shall be shaped horizontally and shall be levelled before filling. For larger sizes of biogas plants (32 m^3 and above) and on weak ground, the foundation ring beam shall be placed with reinforcement bars.
- Horizontal measurements are done with the centre pipe. The 0.5" GI gas pipe shall be placed exactly vertically. The positioning of this center pipe shall be ensured by using a spirit level and adjusting with binding wire fixed at four pegs in the soil on the rim of the excavation. After confirmation of the level, the vertical pipe shall be checked with a plumb to ensure it is still in the exactly vertical position.
- A string or wire shall be attached to the vertical pipe. The length of this wire shall be much longer than the dome diameter.
- The foundation slab shall be placed up to completion at one time, after mixing enough

concrete for the whole slab. The slab shall be exactly leveled with the pegs to determine the level of the concrete at every point around the base. If the slab is not leveled, the distribution of weight will not be balanced and the structure may crack.

2) Digester Wall

- Immediately after casting the slab, the first layer of stonework has to be put into the freshly placed concrete to obtain bonding between foundation and walling.
- The first row of bricks shall be placed on a firm, untouched and level foundation. Subsequent rows shall be positioned on their lengths so that the wall thickness is maintained. The wall thickness shall be maintained at not less than 23 cm.
- The cement mortar for joining bricks shall be mixed in the ratio of 1:4 for cement: sand respectively.
- To construct the digester wall, the radius shall be kept constant using a guide square fixed at the centre GI pipe. All blocks shall be laid out properly with the assistance of the radius square. The radius square shall always be leveled, and a spirit level shall be fixed on the square every time blocks are laid. The dimensions shall be checked and corrected at every stage by measuring the vertical distance from the reference line.
- After the round-wall reaches the correct height, both the inside and outside of the wall shall be plastered carefully with a smooth layer of cement mortar with a mixing ratio of 1:4 for cement: sand respectively. Before application of cement mortar, the wall surface shall be cleaned and moistened, after which the plaster shall be applied in one coat of about 2 cm.
- After every three to four layers of blocks, backfilling and compacting should be done so that the completed part is properly reinforced by the soil. The backfilling between wall and pit-side shall be compacted with great care, not sooner than 12 hours after brick course placement to allow the cement mortar to cure. Earth shall be well compacted by adding water and carefully ramming along the digester.
- The feedstock inlet pipe (or toilet pipe in the case of toilet connected digester) shall be placed in position when the round-wall is 30-36 cm high, at a slope of 45°), taking into consideration the location of the inlet mixing chamber.
- At the opposite of the main feedstock inlet pipe, a window must be left for slurry flow to the expansion chamber. After the space for the outlet is dug out, construction of the vertical wall shall proceed, incorporating the outlet steps. In the case of toilet connected digester, outlet pipe shall be connected to a sewer line for septic tank and adequate space for the pipe shall be left.

3) Dome (Gas holder)

- To construct the spherical dome, another square shall be used to create a bowl shape. The square shall be fixed at the central GI pipe, with proper positioning and leveling. The radius square shall be adjusted during the dome construction by fastening and correcting the distance from the guide pipe. For plastering, 2 cm shall be added to the radius.
- A nail at the head of the square is used to mark the exact distance for brickwork construction. Each brick of the dome is laid against the nail of the radius stick, keeping the top of the brick in the same slope as the direction of the radius stick. The inner edge of the brick shall always form a right angle with the radius stick, and the brickwork will automatically rise in spherical shape.
- The mortar mixing ratio for dome brick laying shall be 1:3 for cement: sand respectively.
- The spherical wall ends with the manhole ring beam. Above this ring beam the neck shall be constructed in masonry work according to the detailed measurements in the drawing. The neck shall be constructed up to completion at one time to avoid any cracks. Flemish bond

shall be used, whereby the orientation of stones is changed from row to row. The best stones shall be selected especially for the neck structure and a perfect jointing shall be done for the neck. The dome shall be durable with internal gas pressure on the spherical structure and the neck. The neck shall be able to withstand the internal gas pressure by its own internal structure. A main gas outlet pipe shall be applied at the neck.

- A lid shall be cast inside the neck structure. The lid shall be reinforced concrete. Four (4) steel handles shall be applied for a concrete lid. The thickness shall be 18 to 20 cm. The gap between the neck and lid shall not exceed 2 cm as a large gap will not be gas-tight. Sealing shall be done later with moist clay. After clay sealing, weak mortar with mixing ratio of 1:8 for cement: sand respectively shall be applied on the top of the lid peripherally for top sealing.
- After casting the lid and feeding feedstock, a water jacket covering the lid of the manhole shall be applied to prevent lid sealing from drying up and for leakage detection.
- The outside of the dome shall be covered with a layer of plaster before covering with earth. Cement plaster shall not be applied under sunlight. The mixing ratio of mortar for rendering plastering shall be 1:5 for cement: sand respectively.
- Before mortar application, the surface of the wall shall be cleaned and moistened. Plaster of 2 cm thickness shall be applied all over the surface of the dome. The plaster shall be cured for more than 12 hours before backfilling.
- After above rendering, the inside plaster of the dome and neck shall be done with the most accurate workmanship to secure gas tightness. Special attention shall be given to ensuring that the surface area of the dome and neck forms a unity, and every inside plaster course shall be done up to completion at one time.
- A wooden trowel with smoothened corners shall be used alongside a conventional trowel to execute a smooth and even surface. All mortar that falls down shall not be used for the dome and neck.
- Before application of the first layer, the surface of the wall shall be cleaned well, and excess mortar removed before starting plaster work. The quality of the sand for plastering the dome shall be “best of the best” and no impurities shall be allowed. The sand for plastering shall also be sieved prior to mixing with cement.
- Seven steps shall be taken for plastering of the dome: (i) Cement-water flushing, (ii) preparation of mortar in 1:4 mixing ratio for cement: sand respectively , (iii) Cement-water flushing, (iv) plaster with water proof compound, with mixing ratio of 1:4 for cement: sand respectively, (v) Cement–water flushing with water proof compound, (vi) plaster with water proof compound, with mixing ratio of 1:3 for cement: sand respectively, and (vii) Cement–water finish with water proof compound. Undertaking the seven steps will ensure that the final cement flushing appears as a very smooth and shiny surface.
- Backfilling shall be in layers of less than 30 cm, and then compacted softly. Any damage to the digester wall shall be avoided. The backfill material must be compactable, and clay or black cotton soil shall not be applied.

8.4.4 Piping Works and Ditches

Piping works shall be conducted according to the work plan. The layout shall be approved by the User and the Client.

All pipe laying works shall be carried out by experienced personnel. The pipes shall be correctly centered and aligned horizontally and vertically just prior to jointing with the mating socket. Any pipe found to be defective shall be marked, removed and replaced. Any damage to pipe linings or coatings shall be repaired by the Contractor. The pipe shall be corrosion resistant and tolerant of high concentrations of methane gas and hydrogen sulfide.

The pipes and fittings shall be of the same brand. They shall be checked and confirmed not to have any leakages. Pipe manufacturer's specifications and recommendations shall be strictly followed for solvent, welded and electrofusion joints.

After the installation of pipeline, the Contractor shall investigate all the gas lines and pipe joints for any blockages and leaks, and conduct repairs.

The Contractor shall check the pipeline for leakage and secure approval from the User before backfilling. All valves and connections shall be checked to ensure there are no leakages.

The piping for gas shall have a slope of 1/100-2/100 (1-2%) to collect and direct moisture towards water traps. Avoid sagging in the pipe line. A moisture remover shall be installed.

Pressure test on the piping system shall be done after the whole system has been laid and the manometer has been installed. This shall be done before backfilling of the pipe trenches.

Both PVC and PPR pipes shall be laid at least 30 cm below the ground level. Special conditions may require deeper installation. Proper compacting during backfilling shall be done in layers, after every 20 cm to protect pipes.

Manholes shall be installed with metal cover or concrete cover with a steel bar handle at intervals of at least 50 m on the pipe line and at corners along the pipe route. A pressure test unit and gas sampling nipple shall be applied with ball cock.

A manometer shall be provided with a pressure scale so that the User can know the possible amount of gas usage.

For cow shed connected digester, ditch from the cow shed shall be modified so that automatic transportation of cow dung and urine is possible by gravity. A ditch shall be arranged to channel and transport feedstock by gravity. The elevation of ditches between the cow shed and digester shall allow to flow downstream from the cow shed towards the digester. If not, modification work shall be done.

Biogas slurry shall be supplied to the garden by gravity. The location of the garden shall be confirmed to be at lower elevation than expansion chamber of digester. A ditch connecting digester expansion chamber to the garden, with a gate along the channel shall be constructed.

For toilet connected digester, the pipe from sewer line shall be connected to digester inlet pipe. Digester outlet pipe shall be connected with a sewer line to the septic tank. Manholes shall be provided for the connection parts.

For toilet connected digester, a separate pit latrine shall be provided for persons taking antibiotics.

8.4.5 Steel and Metal Works

The Contractor shall furnish and install miscellaneous embedded metal works, such as embedded metal frames for duct cover, anchor bolts with accessories, steel pipes for duct, light gage steel ceiling material with zinc chromate metal finish or hot-dipped galvanized, etc.

The Contractor shall furnish and install miscellaneous non-embedded metal works, such as steel-made chain-link fence with pole, entrance gate, etc. All exposed steel surfaces shall be hot-dip galvanized metal.

Oil paint shall be applied onto two layers of primary anticorrosive paint. Sufficient time shall be allowed for drying between each new coat according to manufacturer's instructions.

Rust on metal surfaces, and oil and dirt on surfaces shall be thoroughly removed before installing.

8.4.6 Electrical and Mechanical Works

Wiring work shall be conducted in accordance with "KS662: 2002 Kenya Wiring Regulations".

Insulated cables shall apply "KS 453:2000 Specification for PVC-insulated cables for Electric Power and Lighting".

All power cables shall be of single-core or multi-core, cross-linked polyethylene (XLPE) insulated, PVC sheathed cables with stranded copper conductors. Power cables shall have ample current carrying capacity and shall duly withstand the maximum prospective fault current for a duration of time.

Each cable shall be fitted with a cable identification label at each end. The cables shall be continuous between terminals, and no junction shall be made in the cable ducts and conduits. The cables shall be laid in the cable ducts or conduits after they have been cleaned. Oil or grease shall not be used as a lubricant for cable laying work, but an approved compound may be used for this purpose.

Where the cables and wires are installed in the conduits, they shall be pulled into a conduit as a bundle to avoid twisting and abrasive actions caused by single conductor pulling.

At least 10% spare terminals shall be provided in the terminal blocks.

Proper earthing shall be done with grounding electrodes. Each electrode shall be complete with approved non-ferrous clamps for the connection of earthing conductors. The measurement of each group of grounding electrodes and earth grid shall be provided and back filling shall only be undertaken after inspection.

Biogas engine generator set shall be supplied with specified or above capacity, frequency 50 Hz, power factor 0.8 or higher, protection class IP23 or better, generation efficiency more than 80% and 20 MJ/kWh, with electric starter and ignition system, gas mixer, electronic governor, cooling system, silencer, inlet valve, display panel for output kW, A, V, and rpm. Battery for starting shall be supplied and installed. It shall have warranty time more than 1 year and 8000 running hours. Necessary tool kit for maintenance shall be provided.

The Contractor shall provide detailed guideline for specification, operation and guideline of engine-generator provided from manufacturer.

8.4.7 Excavation, Soil and Waste

Before excavation, the Contractor shall clear and dispose all rubbish and/or any other objectionable matter within the Site. This shall include the removal of existing foundations and other obstructions interfering with the project work, and burning or otherwise disposing of all such materials.

The slope and bottom of all excavation shall be trimmed and cleared of all loose or decomposed material and finished with firm and smooth perpendicular, level, or inclined surfaces as required. The surfaces of the excavation shall be protected from deterioration and be kept clear and uniform. The excavated trench or pit shall be kept well drained of water until and during backfilling operation.

Before all excavation, the contractor shall obtain approval from the user, specifically regarding the location to place excess soil. Avoid accidents while digging near the sides as soil may collapse

If the soil is not suitable for use in embankment and backfilling, the Contractor shall obtain good quality soil for this purpose from borrow pits. The location and areas of borrow pits shall be proposed by the Contractor and approved by the User and the Client.

The soil shall be placed in not more than 30 cm layers evenly spread, and each layer shall be well compacted to attain at least the same degree of consolidation as undisturbed soil in the Site. The soil shall be dried or watered as required to have the optimum moisture content to attain the required consolidation. The surface of embankment and backfill after compaction shall have a slightly cambered surface where required to facilitate drainage.

8.4.8 Auxiliary Tools and Equipment

1) Gas Holder Bag

Gas bags made of Polyvinyl chloride (PVC) or Isobutylene Isoprene Rubber (IIR), more than the specified volume, shall be installed and connected from the gas pipe line. Leakage test shall be conducted. The material of gas bag shall be resistant to acid and alkali corrosion, resistance to wear and friction. Life span shall be more than 10 years. Suitable temperature at 0-50 ^{o}C.

2) Biogas Flow Meter

The gas flow meter recording in m^3 with one decimal place shall be installed each for the outlet of every digester and gas bags. Nominal flow rate shall be up to 2.0 m^3/h. Maximum working pressure shall be more than 10 kPa. Pressure loss shall be less than 200 Pa. Air tightness shall have no leakage under 10 kPa. The same amount of flow meter shall be supplied for the replacement purpose.

3) Biogas filtering unit

Activated carbon filter units to remove hydrogen sulfide, more than 99% purifying efficiency shall be installed for the cow dung digester and human waste digester. The unit container material shall be durable for H_2S corrosion.

4) Manometer

Manometers of highly resistant to corrosion shall be supplied and installed, one in the control chamber of cow dung digester, one in the control chamber of human waste digester, and one in the kitchen.

5) Biogas Stove

Biogas cooking stove shall be in accordance with KS2520:2013 Domestic Biogas Stoves – Specification after it is enforced or other relevant standard. Biogas stove with double burner, with automatic starter switches and 2 meters of hosepipe. Each burner shall have efficiency more than 57%.

8.4.9 Safety Arrangement

The Contractor shall provide insurance for workers. A copy of the certificate of insurance shall be provided to the Client.

Safety equipment shall be provided for all workers and related personnel in the construction site such as helmets and belts. All laborers shall be appropriately dressed for the working conditions to avoid accidents.

The construction site shall be clearly separated from outsiders by a fence or rope. Nobody other than related personnel or laborers shall enter the construction and installation site during works.

The Contractor shall provide maximum warnings to ensure fire hazards are managed. No cigarette smoking shall be allowed on site during works, especially after feedstock has been channeled to the biogas system.

The location of main facilities, such as digester, pipe line, gas bag, and generator shall be apart from traffic line and its extended line of any vehicles to avoid accidental shock.

Fire extinguisher and eye-catching warning sign with shall be attached in power house and other facilities that have possibility of fire.

8.4.10 Testing and Commissioning

The Contractor shall perform testing and commissioning in the presence of the Client. Testing and commissioning shall be according to the format prepared by the Contractor and submitted for approval by the client before testing.

For biogas digesters connected to toilets, in addition to the feedstock supply from toilets, cow dung at

200 kg per digester shall be applied not less than three times to facilitate initial fermentation at the original stage.

8.4.11 User Training

The Contractor shall provide user training to not less than three operator assigned by users' representative. The Contractor shall conduct operation and maintenance work during the testing and commissioning period, with participation of users and provision of O&M training. The training period shall not be less than three weeks. The Contractor shall check the users' understanding by using a questionnaire sheet and attach it in the report to the Client. A list of "Do's and Don'ts" shall be provided and presented to users at the working place. The findings and challenges found in the process of user training shall be pointed out.

Proposed user training program shall be submitted to the Client for approval, before conducting the training.

The Contractor shall provide a list of spare parts and consumables, as well as contact addresses for the same, so that user can easily make contact whenever it is necessary.

If the system contains a digester connected to toilets, notification for toilet usage shall be provided and a briefing meeting shall be held with toilet users. The notification of toilet usage shall include but not be limited to:

- Do not flush excessive amounts of water (specify allowable amount)
- Do not use the toilets connected to the digester while taking antibiotics, use a separate toilet instead
- Do not use detergents with disinfecting agents such as chlorine

Visual guidance shall be provided by pasting a laminated instruction paper on the wall of all entrances and exits of toilets.

User manual for operation and maintenance including daily routines, recording sheets, DOs, DON'Ts, trouble shooting, contact list for spare parts and consumables supply shall be provided and submitted for approval of the Client.

Safety instructions to users shall be provided, especially pertaining to the risk of explosion and toxicity of biogas aspiration.

8.4.12 Record and Documentation

The Contractor shall present his general work plan for approval by the Client.

The list of documents that the Contractor shall submit is as follows:

- Work Plan
- As built drawings
- Format for testing and commissioning
- Record of monitoring (record of input, operation record, gas production, energy generation)
- Program of user training
- User Manual
- Record of user training and user's understanding
- List of consumables and spare parts and supplier's contact list

CHAPTER 9 ENVIRONMENTAL ASPECT

9.1 Environmental Management System in Kenya

9.1.1 National Environment Management Authority (NEMA)

The National Environment Management Authority (NEMA) is a practical official body responsible for managing environment, reviewing “EIA Project Reports” and “EIA Study Reports” and issuing Environment Licenses for development projects in Kenya.

Under the Board and the Director General at the top of NEMA, the Authority has established six departments and one sub-department. Among those departments, the following ones have functions on EIA related activities. (Source, National Environment Management Authority Strategic Plan 2008-2012, June 2009, NEMA)

- ✓ The Director General appoints members of Environmental Impact Assessment Technical Advisory Committee (EIA-TAC) and prescribes the terms of reference and rules of procedure of the review of EIA related reports received by NEMA.
- ✓ The Compliance and Enforcement Department, identifies projects and programmes or types of projects and programmes, plans and policies for which environmental audit (EA) or environmental monitoring must be conducted under the Act and ensure EIAs and EAs are conducted.

9.1.2 Environmental Management System at County Level

(1) Decentralization and Administrative Structure Reform (Transitional Period)

Since the New Kenyan Constitution came into force in 2010, decentralization, administrative structure reforms and regulatory revisions for “Country System” in place of former “Province and District System” have started.

- ✓ As a matter of fact, NEMA issued a public notice with regard to the decentralization of its county functions on EIA as of 1st of July 2012.

As far as reforms of environmental management and EIA review procedure are concerned, the reform processes are in the transitional period as of January 2014.

- ✓ Due to the fact that the environmental management and EIA procedural reforms have not adequately come into effect in order to conform to the new constitutional dispensation especially on administrative units, the provisions of the current EMCA 1999 and EIA/EA Regulations (Amendment) 2009 are still in force until such a time that they will be reviewed. However the NEMA through an administrative procedure has done away with District and Provincial offices and effectively replaced them with County offices.
- ✓ The transition period therefore means that the former systems (especially where the relevant laws are concerned) are still in operation alongside the current administrative re-alignment. Therefore, the former local systems of “Provincial Environmental Committee” as well as “District Environmental Committee” are envisaged to be reviewed.

(2) Provincial Environmental Committee (PEC) & District Environmental Committee (DEC)

According to the current EMCA 1999 and EIA/EA Regulations (Amendment) 2009, NEMA operates at provincial and district levels. Namely the Provincial Environment Committees (PECs) and District Environment Committees (DECs) are a primary mechanism for NEMA to undertake its functions, which will be reviewed to County Environment Committee in order to conform to the new administrative structure of County system.

9.2 EIA procedures and Licensing System of Kenya

9.2.1 Projects Sectors Subject to EIA

Project Sectors subject to EIA procedures in Kenya are specified in the Environmental Management and Coordination Act of 1999 (EMCA) as "Second Schedule" as shown in Table 9.1.

Table 9.2.1 "Second Schedule" Specified in EMCA (Project Sectors Subject to EIA)

Sector	Including	
General	An activity out of character with its surrounding any structure of a scale not in keeping with its surroundings	Major changes in land use
Urban developments	Designation of new townships Establishment of industrial estates Establishment or expansion of recreational areas	Establishment or expansion of recreational townships in mountain areas, national parks and game reserves Shopping centers and complexes
Transportation	All major roads All roads in scenic, wooded or mountainous areas and wetlands, Railway lines	Airports and airfields Oil and gas pipelines Water transport
Dams, rivers and water resources	Storage dams, barrages and piers River diversions and water transfer between catchments	Flood control schemes Drilling for the purpose of utilizing ground water resources including geothermal energy
Aerial spraying.	-	-
Mining	Quarrying and open cast extraction of Precious metal, Gemstones, Metalliferous ores, Coal, Phosphates, Limestone and dolomite	Stone and slate Aggregates, sand and gravel, Clay, Exploration for the production of petroleum in any form, Extracting alluvial gold with use of mercury
Forestry related activities	Timber harvesting Clearance of forest areas	Reforestation and afforestation
Agriculture	Large scale agriculture Use of pesticide Introduction of new crops and animals	Use of fertilizers Irrigation
Processing and manufacturing industries	Mineral processing, reduction of ores and minerals Smelting and refining of ores and minerals Foundries Brick and earth wear manufacture Cement works and lime processing Glass works Fertilizer manufacture or processing Explosive plants Oil refineries and petrochemical works Tanning and dressing of hides and skins Abattoirs and meat processing plants Chemical works and processing plants Brewing and malting Bulk grain processing plants	Fish processing plants Pulp and paper mills Food processing plants Plants for manufacture or assembly of motor vehicles Plant for the construction or repair of aircraft or railway equipment plants for the manufacture or assembly of motor vehicles plants for the manufacture of tanks, reservoirs and sheet metal containers plants for manufacture of coal briquettes plants for manufacturing batteries
Electrical infrastructure	Electrical generation stations Electrical transmission lines	Electrical sub-stations Pumped storage schemes
Management of hydrocarbons	Storage of natural gas and combustible or explosive fuels	
Waste disposal	Sites for solid waste disposal Sites for hazardous waste disposal Sewage disposal works	Works involving major atmospheric emissions Works emitting offensive odours
Natural conservation areas	Creation of national parks, game reserves and buffer zones Establishment of wilderness areas Formulation or modification of forest management policies Formulation of modification of water catchment management policies	Policies for the management of ecosystems especially by use of fire Commercial exploitation of natural fauna and flora Introduction of alien species of fauna and flora Introduction of alien species of fauna and flora into ecosystems
Nuclear Reactors	-	-
Major developments in biotechnology	Introduction and testing of genetically modified organisms	

Source: Environmental Management and Coordination Act of 1999 (EMCA)

However, "Second Schedule" does not specify the scale and size of each project. Namely without reference to scale or size of a project fall under the Second Schedule, such a project shall go through the EIA procedures.

(1) Renewable Energy Projects and necessity of EIA

Renewable Energy Projects (PV, Mini hydro, Bio-gas and Wind power systems) which falls under "No. 10 Electrical Infrastructure" in the "Second Schedule" of EMCA. Therefore, all Renewable Energy Projects are naturally subject to the EIA procedures.

(2) Draft NEMA EIA Guidelines and Administration Procedures

In addition, NEMA developed a Draft EIA Guidelines and Administration Procedures in November 2002 in response to the National Policy on Environment and EMCA 1999. The NEMA Draft EIA Guidelines provides procedural guidelines for,

- ✓ Implementation of EIA
- ✓ Monitoring and Environmental Audit (EA)
- ✓ Strategic Environmental Assessment (SEA)
- ✓ Issues of Trans-boundary, Regional and International Conventions, Treaties and Agreements
- ✓ Steps in EIA studies and Environmental Audits
- ✓ The contents and format of the study reports to be submitted to NEMA
- ✓ The EIA study review process and decision-making, and
- ✓ Others.

CHAPTER 7 of the NEMA Draft EIA Guidelines mentions that Lead agencies are mandated by section 58 of the EMCA 1999, in consultation with the Authority to develop EIA Guidelines to ensure that environmental concerns are integrated in sector development policies, plans, projects or programmes. The sector guidelines shall focus on specific mandates in line with the statutory relationships with the administration of the EIA process.

- ✓ However, such sector guidelines have not been developed by relevant lead agencies excluding the sector of petroleum (Source, A meeting with NEMA HQ).
- ✓ In addition, the Draft Guidelines is rendered a rather conceptual guidance. Practically, the processes of EIA and the licensing shall refer to EIA/EA Regulations (Amendment) 2009.

9.2.2 EIA Review Process and Licensing

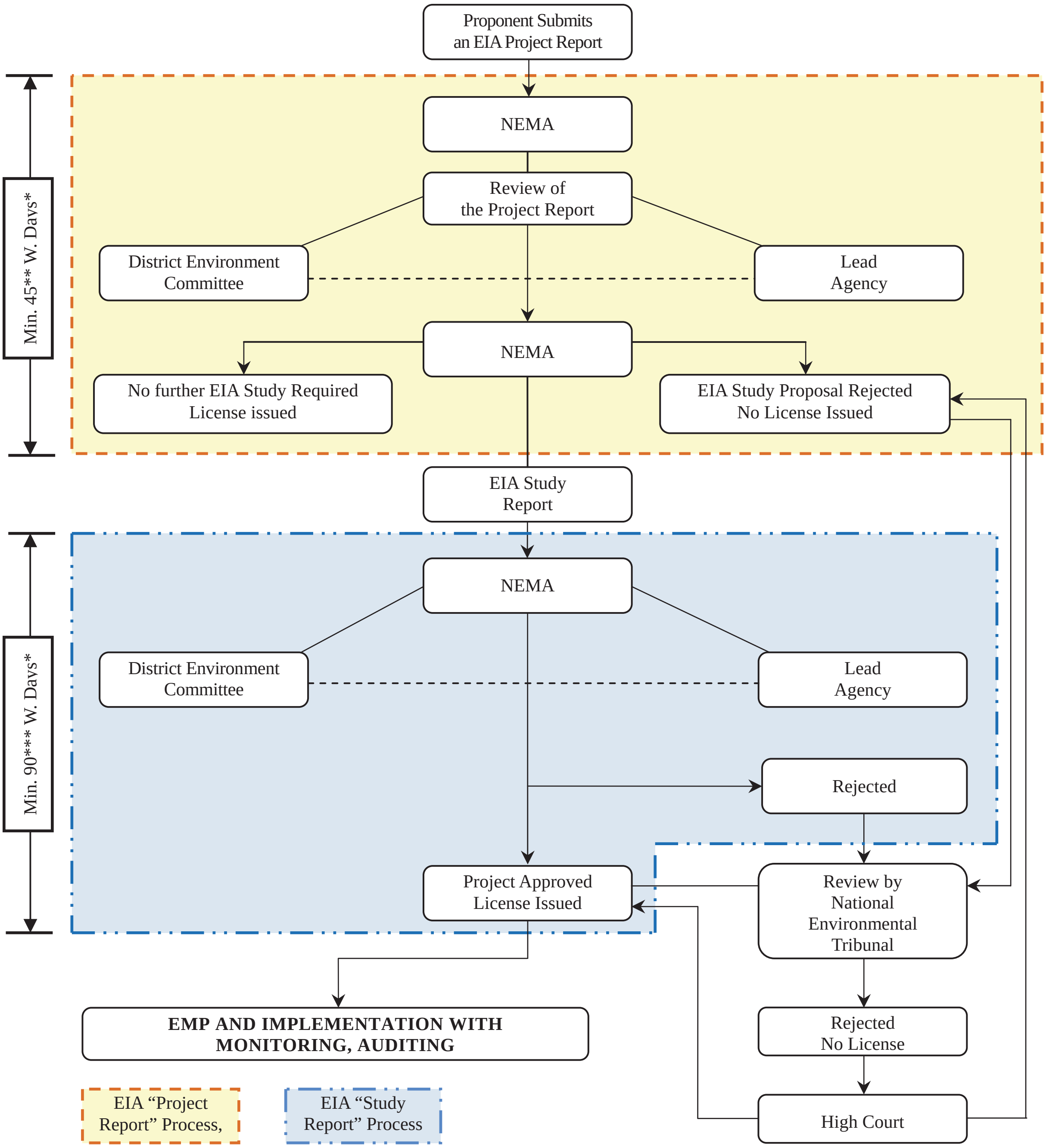
The Environmental Management and Coordination Act of 1999 (EMCA) and EIA/EA Regulations (Amendment) 2009 specify the EIA Review process which consists of the following two steps.

- ✓ EIA "Project Report" Process
- ✓ EIA "Study Report" Process

(1) Overview of the EIA Process

Based on EMCA 1999, EIA/EA Regulations (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, Kenyan EIA entire procedures can be depicted as shown in the figure in the next page.

Detail flows of "EIA Project Report" and "EIA Study Report will appear afterward.



*Note; *According to NEMA, "days" in the procedures stands for "Working days"*
*** According to NEMA, not "within forty-five days" but "Minimum forty-five days" for the EIA Project Report Review and Licensing period*
**** According to NEMA, not "within 90 days" but "Minimum 90 Working days" for the EIA Project Report Review and Licensing period*

Source, NEMA, (modified by the JICA Expert Team based on discussions with NEMA HQ officials)

Figure 9.2.1 Overview of the EIA Process

(2) EIA "Project Report"

According to EMCA 1999, EIA/EA Regulation (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, the EIA "Project Report" Process can be summarized as follows and depicted in Figure 9.3.

- ✓ The process starts by a project proponent, selecting a consultant which must be licensed and registered with NEMA as a Lead Expert on EIA/EA
- ✓ An EIA "Project Report" shall be prepared by the consultant (Registered Lead Expert on EIA/EA). The following shows contents to be stated in the "Project Report".

Table 9.2.2 Contents of the Project Report

Nature of the project Location of the project including the physical area that may be affected by the project's activities Activities that shall be undertaken during the project construction, operation and decommissioning phases Design of the project Materials to be used, products and by-products, including waste to be generated by the project and the methods of their disposal Potential environmental impacts of the project and the mitigation measures to be taken during and after	implementation of the project Action plan for the prevention and management of possible accidents during the project cycle Plan to ensure the health and safety of the workers and neighbouring communities Economic and socio-cultural impacts to the local community and the nation in general Project budget Any other information the Authority may require

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- ✓ The proponent shall submit at least ten copies and one soft copy (CD-ROM) of the EIA "Project Report" to the Authority (NEMA HQ or its County Office(s)) accompanied by the prescribed fees of 0.05% of the project cost. (50% of the 0.05 of the project cost paid at the time of submission of the EIA "Project Report" and the remainder of 50% paid at the time of collection of license)
- ✓ The Authority shall **within seven (7) days** upon receipt of the project report, where the "Project Report" conforms to the requirements of regulation, distribute a copy of the "Project Report" to Relevant Lead Agencies and Relevant District Environment Committee(s) (DEC(s)) for their review and written comments.
- ✓ Those comments of Lead Agencies and DECs shall be submitted to the Authority **within twenty one (21) days** from the date of receipt of the "Project Report" from the Authority, or such other period as the Authority may prescribe.
- ✓ On receipt of the comments or where no comments have been received **by the end of the period of thirty (30) days** from the date of receipt of the "Project Report", the Authority shall proceed to determine the project report.
- ✓ On determination of the "Project Report", the decision of the Authority, together with the reasons thereof, shall be communicated to the proponent **within forty-five (45) days**[3] of the submission of the "Project Report".
- ✓ Where the Authority is satisfied that the project will have no significant impact on the environment, or that the project report discloses sufficient mitigation measures, the Authority may issue a license
- ✓ If the Authority finds that the project will have a significant impact on the environment, and the project report discloses no sufficient mitigation measures, the Authority shall require that the proponent undertake an EIA study.

3 According to NEMA, not "within forty-five days" but "Minimum forty-five days" for the EIA Project Report Review and Licensing period

- ✓ A proponent, who is dissatisfied with the Authority's decision that an environmental impact assessment study is required, may **<u>within fourteen (14) days</u>** of the Authority's decision appeal against the decision to the Tribunal.

(1) EIA "Study Report"

According to EMCA 1999, EIA/EA Regulation (Amendment) 2009 and discussions with NEMA officials as well as considering the decentralization of NEMA's functions at the County level, the <u>EIA "Study Report"</u> Process can be summarized as follows and depicted in the above figure.

- ✓ An EIA study shall be conducted in accordance with a TOR (Terms of Reference) to be developed during the "Scoping" exercise, Then the TOR shall be submitted to be approved **<u>within seven (7) days</u>** by the Authority, Every EIA study shall be carried out by an EIA/EA Lead Expert
- ✓ During the process of conducting an EIA study, the proponent shall in consultation with the Authority, seek the views of persons who may be affected by the project.
- ✓ Namely, holding at least three public meetings with the affected parties and communities to explain the project and its effects, and to receive their oral or written comment
- ✓ A proponent shall submit to the Authority, an environmental contents of EIA "Study Report" incorporating but not limited to the following information:

Table 9.2.3 Contents of the Study Report

Proposed location of the project Concise description of the national environmental legislative and regulatory framework, baseline information, Any other relevant information related to the project, the objectives of the project Technology, procedures and processes to be used, in the implementation of the project Materials to be used in the construction and implementation of the project Products, by-products and waste generated project Description of the potentially affected environment Environmental effects of the project including the social and cultural effects and the direct, indirect, cumulative, irreversible, short term and long-term effects anticipated Alternative technologies and processes available and reasons for preferring the chosen technology and processes Analysis of alternatives including project site, design and technologies and reasons for preferring the	proposed site, design and technologies Environmental management plan proposing the measures for eliminating, minimizing or mitigating adverse impacts on the environment, including the cost, time frame and responsibility to implement the measures, Provision of an action plan for the prevention and management of foreseeable accidents and hazardous activities in the cause of carrying out activities or major industrial and other development projects, Measures to prevent health hazards and to ensure security in the working environment for the employees and for the management of emergencies Identification of gaps in knowledge and uncertainties which were encountered in compiling the information Economic and social analysis of the project Indication of whether the environment of any other state is likely to be affected and the available alternatives and mitigating measures Such other matters as the Authority may require

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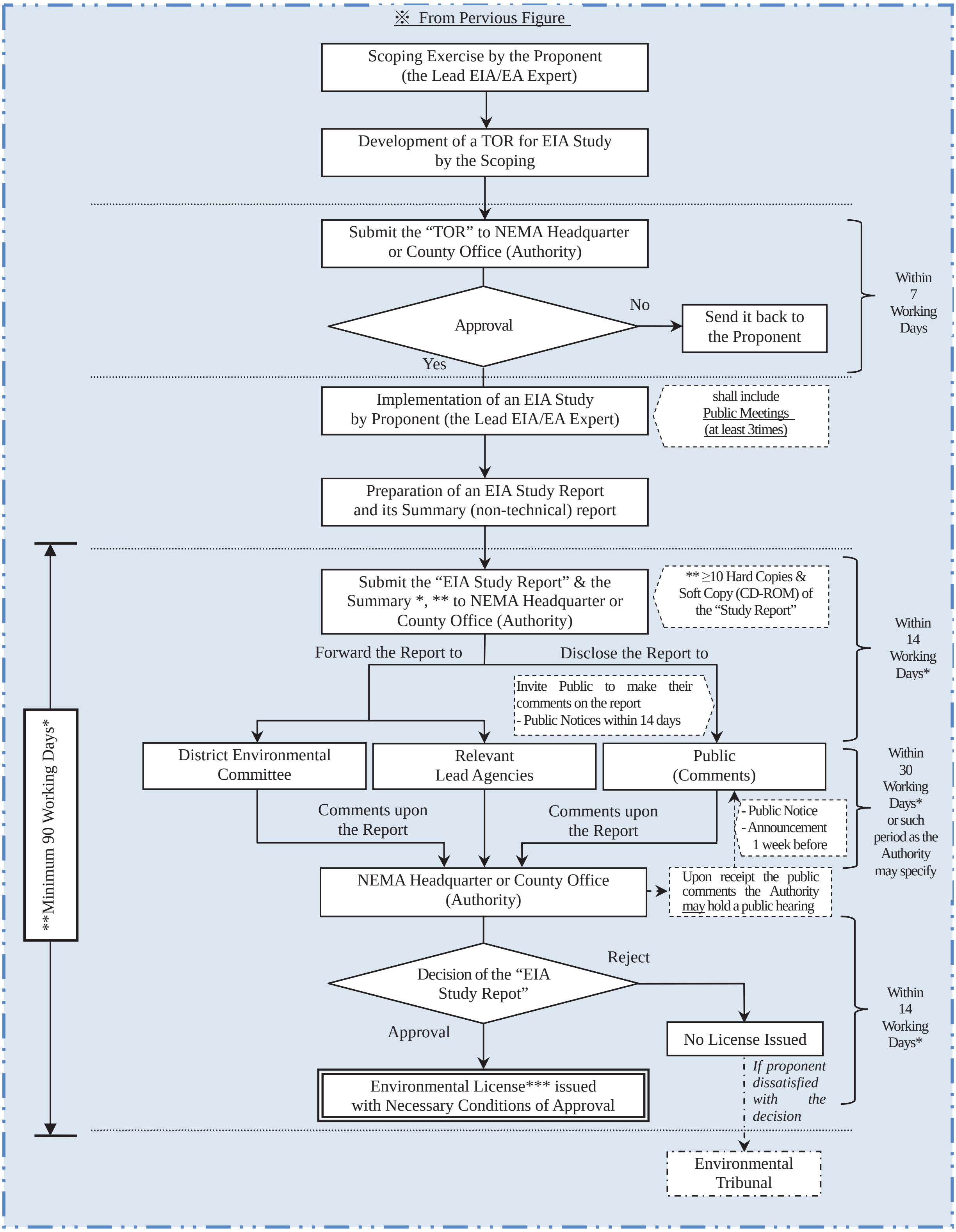
- ✓ EIA "Study Report" shall be accompanied by a non-technical summary outlining the key findings, conclusions and recommendations of the study, Proponent shall submit ten copies and a soft copy (CD-ROM) of an EIA "Study Report" to the Authority
- ✓ The Authority shall **<u>within fourteen (14) days</u>** of the receipt of the EIA "Study Report" submit a copy of the report to any Relevant Lead agencies as well as District Environmental Committee(s) (DEC(s)) for their comments.

- ✓ Upon receiving the EIA "Study Report", the lead agencies and DEC(s) shall review the report and shall thereafter send their comments on the "Study Report" to the Authority **within thirty (30) days** or such extended period as the Authority may specify.
- ✓ The Authority shall **within fourteen (14) days** of receiving the EIA "Study Report", invite the public to make oral or written comments on the report, at the expense of the proponent.
- ✓ Upon receipt of these comments, the Authority may hold a public hearing
- ✓ The Authority shall give its decision on EIA "Study Report" **within three (3) months** of receiving an EIA "Study Report"
- ✓ Where the Authority approves an EIA "Study Report" , it shall issue an EIA license on terms and conditions as it may deem necessary
- ✓ A person who is aggrieved by the decision may appeal to the Tribunal against the decision.



Note: **According to NEMA, "days" in the procedures stands for "Working days"*

*** According to NEMA, not "within 90 days" but "Minimum 90 Working days" for the EIA Project Report Review and Licensing period*

*** 50% of the 0.05 of the project cost paid at the time of submission of the EIA Project Report and the remainder of 50% paid at the time of collection of license

Source, Prepared by the JICA Expert Team referring to the EIA/EA Regulations (Amendment) 2009 and based on discussions with NEMA

Figure 9.2.3 EIA Study Report Review Process and Duration

(4) Public Comments and Public Hearing in the EIA Study Report Process

Table below shows differences between "Public Comments" and "Public Hearing" in the course of the EIA Study Report Process. Both public comments and public hearing are means of public consultation.

Table 9.2.4 Public Comments and Public Hearing in EIA Study Report Process

Public Comments	Public Hearing
· Invitation is done both at the time of conducting EIA and after submission of Study report	· Conducted only after submission of the EIA study report at NEMA offices
· Invitation of public comments must be done as follows · At least three public meetings for comments must be done by the EIA consultant in the course of the study · One public comments window after submission of EIA study report at NEMA office	· Public hearing done only once after submission of EIA study report
· Comments are received both by EIA consultant and NEMA	· Sessions for public hearing only organized by NEMA and the report of the public hearing only prepared by the presiding NEMA official
· Invitation for public comments is mandatory as per the regulations	· Conducting public hearing sessions is at the discretion of NEMA based on the nature of the proposed study and adequacy of the study report

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(5) Possible Schedule of EIA Review Process and Licensing for Renewable Energy Projects

In accordance with EIA processes noted above, a possible schedule of EIA reviews and licensing for renewable energy projects can be depicted as a bar-chart shown in the figure below.

Item		1st Month	2nd Month	3rd Month	4th Month	5th Month	6th Month	7th Month	8th Month	9th Month
1.1	**Selection of Lead EIA/EA Expert(Consultant)**									
2. EIA Project Report	2.1 **Environmental Study, Survey& Report Preparation.**									
	2.2 **Lands Adjudication /Coordination**									
	2.3 **EIA Project Report Submission to NEMA**			▲						
	2.4 **EIA Project Report Reviews and Approval by NEMA**			Min. 45	Working Days					
	2.5 **Determination by NEMA (Project Repot is approval or EIA study process)**				▲	Approved: Licence or EIA is required move to 3. below ↓				
3. EIA Study Report	3.1 **Scoping/TOR for EIA**									
	3.2 **Submission of TOR to NEMA**					▲				
	3.3 **TOR Approval by NEMA**					7 W. Days				
	3.4 **EIA Study, Survey, and Report Preparation**									
	3.5 **EIA Study Report Submission to NEMA**						▲			
	3.6 **Acceptance of EIA Study Report/Distribution to Relevant Agencies and Committee**							14W. Days		
	3.7 **Invitation & Receiving of Public Comments**							30	W. Days	
	3.8 **EIA Study Report Reviews by Lead Agencies and Committee**							30	W. Days	
	3.9 **Decision of EIA Study Report of Communication to Proponent**								14 W.	Days ▲
	3.10 **Licensing**									▲ Licence

Min. 90Working. Days

Prepared by JICA Expert Team

Figure 9.2.4 Possible Schedule for EIA/Environmental Licenses

(6) Revision of EMCA and EIA/EA Regulation in 2014

In light of the new constitution enacted in 2010, the relevant laws and regulations, especially EMCA 1999 and the EIA/EA regulations 2009 are being reviewed (as of January 2014) to conform to the expectations of the new constitution. Therefore, revised EMCA and EIA/EA regulations may be applied for relevant projects after 2014. For more details, contact to NEMA on the revisions.

9.3 Specific Subject (Solid Waste Management)

Solid waste management issues shall be addressed in compliance with the following laws and regulations in Kenya.

- ✓ Environmental Management and Coordination Act of 1999 (EMCA)
- ✓ Environmental Management and Coordination (Waste Management) Regulations 2006
- ✓ Guidelines for E-Waste Management in Kenya 2010
- ✓ Others (if any)

9.3.1 Construction Stage

All trash and packaging materials which might result from the construction process will be collected by the contractor(s) for adequate disposal, which shall be one of the prerequisites for the contract(s) for the contractor(s) to be employed. In this regard, the solid waste management during constriction stage can be secured as follow.

- ✓ REA is required to instruct contractor(s) to make sure such solid waste management.

9.3.2 Operation Stage

Replacement of used batteries, fluorescent tubes and other electrical appliances shall be managed by each project facility. REA is required to have discussions with each facility, and/or initiate stakeholder meetings in each site to discuss and find solutions for management of such solid waste as follows.

(1) E-waste

The issues of “e-waste management” are prominent. Especially e-waste components like used batteries, used fluorescent lamps and other used electrical appliances including PV solar panels, inverters and etc. are the core issues as summarized in the table below.

Table 9.3.1 E-waste Components in Renewable Energy Projects

E-waste	Hazardous Element
Used Lead-acid batteries	Lead and Sulfuric Acid
Used Fluorescent tubes	Mercury
Used PV panels, Inverters and Other appliances	Other Heavy Metals

Prepared by JICA Expert Team

(2) Hazardous and Non-Hazardous Elements

Hazardous elements and Non-Hazardous Elements in the table below are regulated by EMCA, especially by the Guidelines for E-Waste Management in Kenya.

Table 9.3.2 Hazardous Elements in Electrical and Electronic Equipment

Element	For example found in electrical and electronic equipment such as:
Americium	Smoke alarms (radioactive source)
Mercury	Fluorescent tubes (numerous applications); tilt switches (pinball games, mechanical doorbells, thermostats)
Sulfur	Lead-acid batteries
PCBs	Prior to ban, almost all 1930s-1970s equipment, including capacitors, transformers, wiring insulation, paints, inks and flexible sealants used PCBs.
Cadmium	Light-sensitive resistors, corrosion-resistant alloys for marine and aviation environments and nickel-cadmium batteries.
Lead	Old solder, CRT monitor glass, lead-acid batteries and formulations of PVC.
Beryllium oxide	Filler in some thermal interface materials such as thermal grease used on heat sinks of CPUs and

	power transistors, magnetrons, X-ray-transparent ceramic windows, heat transfer fins in vacuum tubes, and gas lasers.
Polyvinyl chloride	PVC contains additional chemicals to change the chemical consistency of the product. Some of these additives can leach out of vinyl products e.g. plasticizers that are added to make PVC flexible.

Source: Guidelines for E-Waste Management in Kenya, December 2010, National Environmental Management Authority

Table 9.3.3 Non hazardous Elements in Electrical and Electronic Equipment

Element	For example found in electrical and electronic equipment such as:
Tin	Solder, coatings on component leads.
Copper	Copper wire, printed circuit board tracks, component leads.
Aluminium	Nearly all electronic goods using more than a few watts of power, including electrolytic capacitors
Iron	Steel chassis, cases, and fixings.
Germanium	1950s-1960s transistorized electronics (bipolar junction transistors).
Silicon	Glass, transistor, ICs, printed circuit boards.
Nickel	Nickel-cadmium batteries.
Lithium	Lithium-ion batteries.
Zinc	Plating for steel parts.
Gold	Connector plating, primarily in computer equipment.

Source: Guidelines for E-Waste Management in Kenya, December 2010, National Environmental Management Authority

Possibility of “hazard to health and environment” caused by the hazardous elements shown in the table above, which is one of the reasons for the necessity of e-waste management.

(3) Handling Procedure of E-waste

Not like domestic waste which is generated daily, e-waste is generated after life span of each component of the project facilities has finished.

Namely, the life span of batteries and fluorescent lamps are about two to several years as well as electrical appliances including PV solar panels, inverters and etc. are several to 10-25 years for which deposals shall be handled as summarized in the table below.

Table 9.3.4 Handling Procedure of E-waste

Component	Possible Life Span*(years)	Handling	Remarks
Battery	3 to 8	・In order to prevent diffusion of toxic substances in batteries, used ones shall safely be kept without damage (Do not Crash! Do not Take Apart!) until properly dispose them. ・Used batteries can be sold to licensed e-waste handlers and/or battery producing companies in Kenya	・Licensed e-waste handlers (See Table 9.3.5) or contact each NEMA county office to get more fresh information of such handlers ・Battery Producing Companies (See Figure 9.3.1 or contact each NEMA county office) ・Purchase Prices are subject to the market trends
Fluorescent Lamp	2 to 4	・In order to prevent diffusion of mercury in fluorescent lamps, used ones shall safely be kept without damage (Do not Crash! Do not Take Apart!) until properly dispose them. ・Used Fluorescent Lamps shall be transported to licensed e-waste handlers in Kenya to be disposed.	・Licensed e-waste handlers (See Table 9.3.5) or contact each NEMA county office to get more fresh information of such handlers
LED Lamp	5	・Used LED Lamps shall be transported to registered e-waste handlers in Kenya to be disposed.	
PV Solar Panel	20 to25	・Used PV Solar Panels shall be transported to registered e-waste handlers in Kenya to be disposed.	
Inventor	5 to 10	・Used Inventor shall be transported to licensed e-waste handlers in Kenya to be disposed.	

* Note: Vary depending on the intended use as well as status of use

Prepared by JICA Expert Team

Photo by JICA Expert Team

A battery maker already has a program of buying used batteries at Kenya shillings 40 per kilogram

Figure 9.3.1 Old Battery Purchasing by a Battery Maker

Table 9.3.5 Licensed E-waste Handlers in Kenya (As of August 2013)

Handler	Contact	District	Waste Type
EAST AFRICA COMPUTER RECYCLERS LTD	P.O .BOX 49266-00100, NAIROBI Email: eastafricancomputer@yahoo.com 07215036515 0729308221	MOMBASA	ELECTRONIC RECYCLING
WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT CENTER	P.O .BOX 48584-00100 NAIROBI Email: info@weecenter.com 0733-986-558 202060921	NAIROBI	ELECTRONIC RECYCLING

Source: NEMA (tabulated by JICA Expert Team)

(4) E-waste Management Structure

Used batteries, fluorescent tubes and other used electrical apparatuses/devices can be handled by organizing an e-waste management sub-committee under the Pilot Project management structure to be set up by each community and/or facility as follows.

a. The structure (sub-committee) to be organized for the e-waste management shall be discussed among stakeholders on the initiative of REA.
b. Each community is to be enlightened that even the electrical apparatuses/devices such as PV panels and inverters which have a longer lifespan eventually need replacement
c. Each community is to also be enlightened that those hazardous elements shown in Table 9.3.2 are hazardous to health and environment as well as some hazardous substances like “lead” in batteries and some no-hazardous elements shown in Table 9.3.3 can be recycled and reused.

(5) E-waste Disposal System

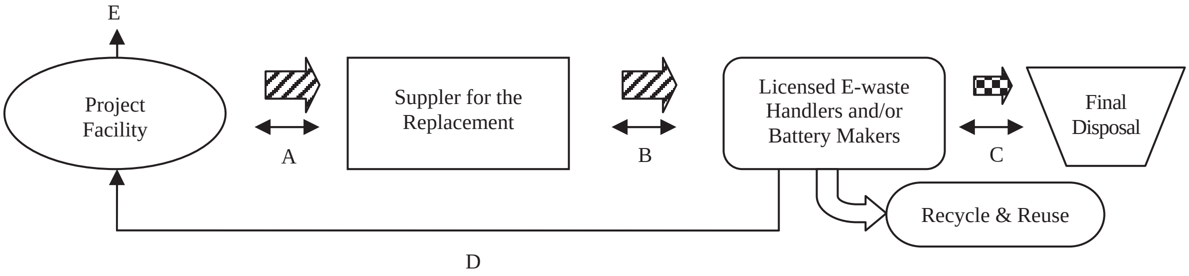
Practically, those e-wastes shall be transported to the licensed E-waste Handlers and/or battery makers in the following idea.

a. Request suppliers to take away used ones from each facility when carrying out replacements (this shall be set as a condition for carrying out replacements).
b. Due to the public property, earning from the selling of used batteries and other used substances of e-waste shall be remitted using the “m-pesa” system by the suppliers when getting selling money from the licensed E-waste Handlers and/or battery makers.
c. The earning money shall be kept in each facility as revenue.
d. In order to make sure the proper transportation and treatment, an e-waste manifest system shall be introduced in the e-waste disposal system as shown in the figure and table below.

* Manifest system: A system to keep all logs from e-waste discharge stage to transportation as well as final treatment in order to prevent illegal dispose of e-waste during the transportation as well as to make sure appropriate final treatment of such waste.

** The following web site of USEPA on Hazardous Waste Manifest System can be referred as reference.

http://www.epa.gov/waste/hazard/transportation/manifest/index.htm



Flow of e-waste

Residue of e-waste after treatment for recycle and reuse.

Logs and records

A	Keep two logs on e-waste between Generator (facility) and Suppler which will transport e-waste to the (2 logs: one is for the generator and one is for the suppler)
B	Keep two logs on the e-waste between the Suppler and Licensed e-waste handler and/or Battery Maker for the treatment of the e-waste (2 logs: one is for the suppler and one is for the Licensed E-waste Handlers and/or Battery Makers)
C	Keep two logs on the reside of the e-waste between the Licensed e-waste handler and/or Battery Maker and a final disposal site (2 logs: one is for the Licensed e-waste handler and/or Battery Maker and one is for the final disposal facility like a landfill)
D	Send two copies of the logs of B and C to Generator (project facility) by which each project facility can identify the proper transportation, treatment and final disposal of the e-wastes by mail.
E	After receiving the copies in D, each facility shall report showing one of the copies to REA, as well as regulatory agency such as Ministry of Education (for Primary Schools) or Ministry of Health (for Dispensaries).

Prepared by JICA Expert Team

Figure 9.3.2 Conceptual Diagram of E-waste Manifest system

Table 9.3.6 Draft E-waste Manifest Log From

	Date:		No. of Manifest	
1	Facility (Generator)	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	E-waste	name 1:	quantity	mode of packing
		name 2:	quantity	mode of packing
		name 3:	quantity	mode of packing
		name 4:	quantity	mode of packing
		name 5:	quantity	mode of packing
2	Suppler (Transportation)	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the above listed e-waste from the Facility on date and Sign			
3	Licensed E-waste Handler and/or Battery Maker	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the above listed e-waste from the Suppler on date and Sign			
	Treated appropriately the e-waste on date and Sign in compliance with the relevant laws and regulations in Kenya, especially the followings ✓ Environmental Management and Coordination Act of 1999 (EMCA) ✓ Environmental Management and Coordination (Waste Management) Regulations 2006 ✓ Guidelines for E-Waste Management in Kenya 2010			
4	Final Disposal	Name	Address/TEL/FAX	
		Person –in Charge:	Contact address/TEL	
	Received the residues of above listed e-waste from the Licensed E-waste Handler and/or Battery Maker on date and Sign			
	Disposed the residues on date and Sign n compliance with the relevant laws and regulations in Kenya, especially the followings ✓ Environmental Management and Coordination Act of 1999 (EMCA) ✓ Environmental Management and Coordination (Waste Management) Regulations 2006 ✓ Guidelines for E-Waste Management in Kenya 2010			

Note: At least eight copies are necessary

Prepared by JICA Expert Team

GUIDELINE FOR BIOGAS GENERATION

PART-II
GUIDELINE FOR OPERATION AND MAINTENANCE

PART-II USER GUIDELINE FOR BIOGAS GENERATION OPERATION

CHAPTER 1 GENERAL

Part-II User Guideline for Biogas Generation Operation is prepared as the reference document for generation and operation and maintenance of the biogas generation system by users. This guideline for users incorporates general operation, maintenance, safety, and daily recording requirements

A customized user manual should be provided by the supplier/contractor installing the biogas system, according to the particular system requirements.

CHAPTER 2 COMPONENTS OF BIOGAS GENERATION SYSTEM

2.1 Biogas System Components

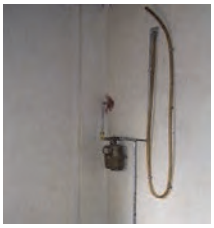
A biogas system utilizes methane produced in a closed container or structure. When a container is perfectly sealed, feedstock (such as cow dung or human waste) is fermented and methane (energy for cooking fuel and electricity) is produced.

A biogas system consists of: biogas digester, expansion chamber, pipeline, moisture remover, gas flow meter, biogas filter, gas bag engine and generator (gen-sets), electricity meter, electric board and breaker, and biogas cooking stove. The following table summarizes the biogas system components and their functions.

Table 2.1.1 Biogas Components and Function

Photo	Name	Function
	Biogas digester	Feedstock (cow dung or human waste) is fermented in a closed dome and methane (energy for cooking fuel and electricity) is produced.
	Feeding chamber	Feeding chamber is for input of feedstock, where users mix raw cow dung with water. This is not installed in a toilet-connected digester.
	Expansion chamber	Expansion chamber is where biogas slurry produced after digestion comes out of the digester. This is not installed in a toilet-connected digester.
	Moisture remover	Biogas has moisture content. Between digester and stove or generator, moisture needs to be removed in a pipe line. The moisture remover is installed in the pipeline to remove moisture.

Photo	Name	Function
	Gas flow meter	Gas flow meter measures the amount of biogas produced in m^3. The meter reading should be recorded every day. If gas flow meter is corroded by biogas, it will need to be replaced.
	Biogas bag	Biogas is produced continually but consumption of the biogas for generation or cooking is only at certain times. Biogas bag is installed to store produced biogas.
 	Biogas filter	Biogas contains hazardous and corrosive hydrogen sulfide, which needs to be removed from biogas. To remove hydrogen sulfide, biogas filter is used. There are two types of biogas filters; activated carbon filter (left) and steel wool filter (right). The former has longer lifespan and is applied in larger systems.
	Biogas engine (connected with generator)	For generation, biogas engine-generator is applied. For systems more than 10 kW, biogas engine and generator set (gen-set) is applied. For smaller systems in the scale of 1-5 kW, a petro engine can be applied with customization.
	Biogas generator	For biogas generation, biogas generator is connected to engine to utilize motive power for electricity generation.
	Electric board and breaker	Electric board is installed for electric power distribution to particular loads. A breaker is installed to switch off the system when biogas generator is not in use.
	Energy meter	Energy meter counts accumulated amount of generated electric energy. The energy meter reading should be recorded every day.

Photo	Name	Function
	Manometer	A manometer indicates biogas pressure for biogas stove. This informs the user about the amount of biogas available. A simple manometer consists of a transparent hose with a brass spigot at the biogas inlet and a metal clip at the end of the hose.
	Biogas cooking stove	Since calorific value of biogas is different from that of other gases such as LPG, the air intake ratio required for its combustion is different from that of general cooking stoves. It is therefore necessary to customize biogas cooking stoves; and these are available in the Kenyan market.

An example of overall system components is shown in the figure below. The system components vary depending on the design; which is made according to site conditions.

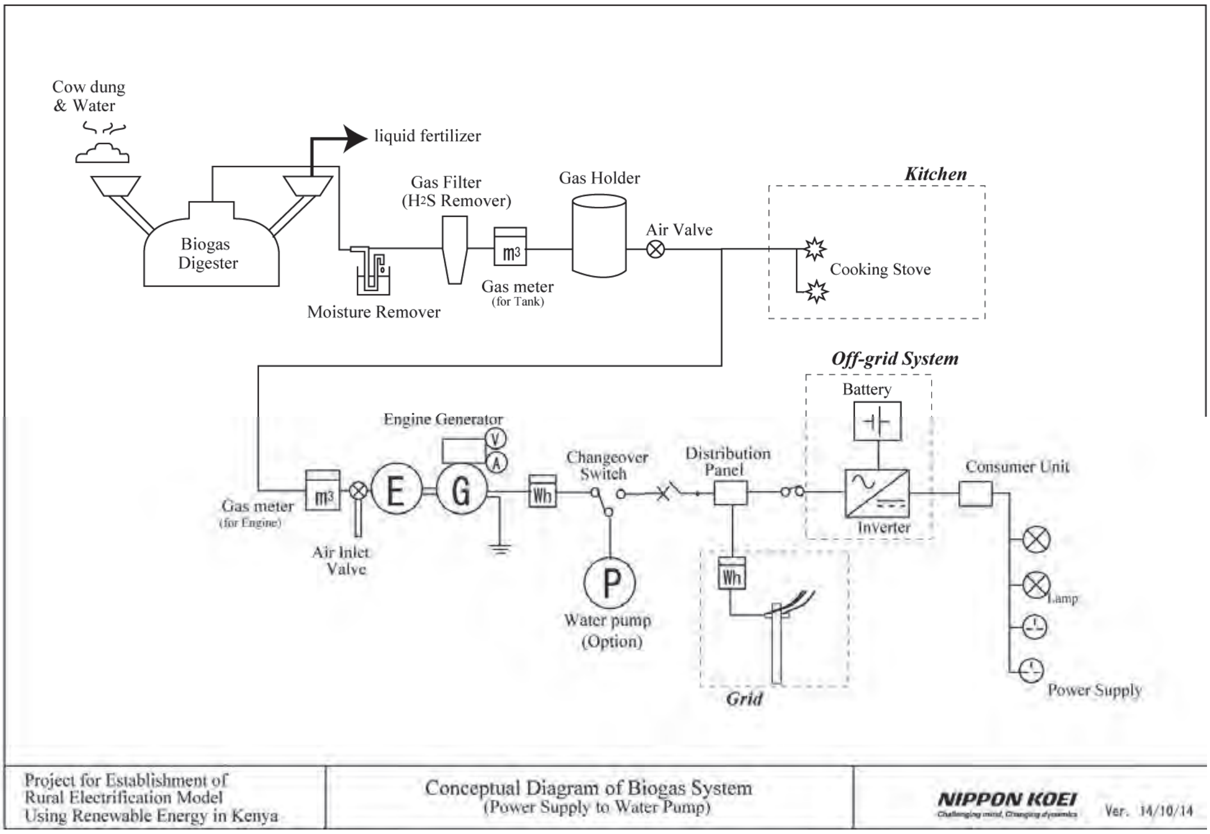


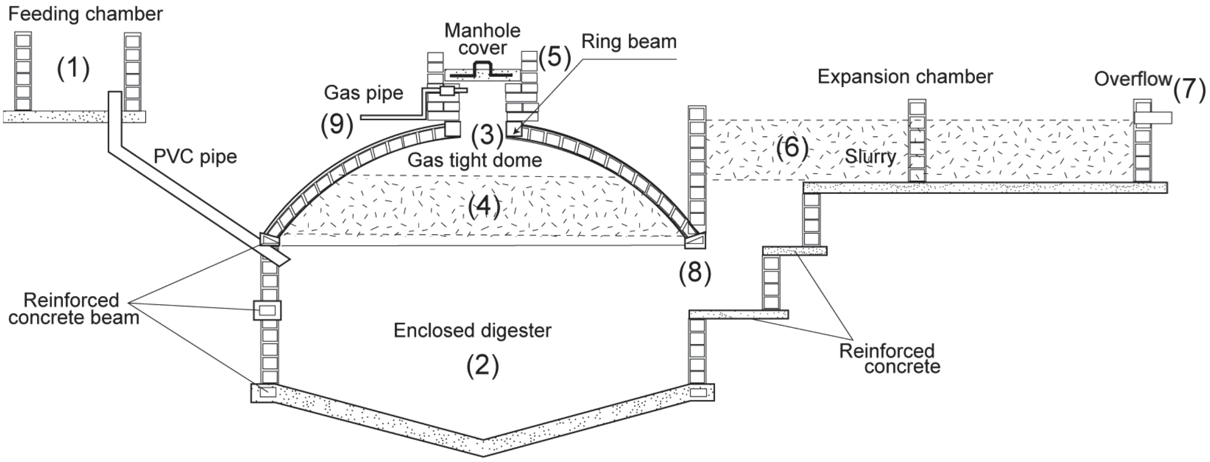
Figure 2.1.1 Example of Biogas System Components

2.2 Biogas Digester

The fixed-dome type of biogas digester consists of the following components:

1) Mixing and feeding chamber
2) Enclosed digester

3) Gas tight dome
4) Fixed gas space
5) Neck on top
6) Expansion chamber
7) Overflow
8) Window for slurry to flow out
9) Gas pipe
10) Inside lower level of slurry



Source: Modified by WG, referring to Biogas Construction Manual (2011), GIZ, GmbH, and PSDA

Figure 2.2.1 Biogas Digester Components

The details of biogas digester components vary according to the supplier’s design. Feedstock and water are mixed in the Feeding Chamber (1). This is the biogas substrate which is digested at (2). The gas produced by bacteria in the digester is stored in the dome (3). The byproduct of digestion (slurry) flows to the expansion chamber (6). The slurry then flows to a garden or septic tank (7). The gas is collected at (3) and transported through gas pipe (9) to pipeline. When gas increases in the digester, slurry flows out through the “window” (8). When gas is used through the gas pipe (9), slurry flows back into the digester through the “window” (8).

The volume of the expansion chamber (6) is equal to the volume of the gas storage (4). When biogas is produced at (3), gas pressure is created by the difference of the two liquid levels, between the inside lower level of the slurry (10) and the overflow level (7). Thus the maximum gas pressure is determined by the difference between overflow level and upper edge of the “window” (8). The window or vent also functions as an overpressure valve. A manhole (5) is attached for the maintenance of digester and removal of scum or refreshment of substrate.

When a biogas plant is underfed, the gas production will be low. In this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. It is important to design the plant keeping hydrostatic pressure higher at the inlet tank than the outlet tank. The hydrostatic pressure from slurry in the inlet and outlet tanks will pressurize the biogas accumulated in the dome. If the biogas plant is overfed, the available volume for biogas will be occupied by feedstock and slurry, and the slurry may enter the gas pipe and flow to the appliances.

A digester for cow dung feedstock application is connected to the cow shed. To enable the transportation of cow dung and cow urine to the digester, an open ditch is connected from the cow shed to the feeding chamber. The open ditch should enable gravitational flow of the feedstock.

Figure 2.2.2 Open Ditch and Connection to Feeding Chamber

For digesters connected to toilets, a pipe line is connected from toilets directly to digester. It is necessary to install manholes.

2.3 Biogas Bag

Biogas is produced continually at a certain rate. For example, if 200 kg cow dung is input and 6 m^3/day gas is generated, the flow will be around 0.25 m^3/h (varying with temperature). However, consumption for generation or cooking is only at certain times, 1-2 hour per a day. Biogas bag is therefore installed to store the produced biogas.

Biogas bag is made of plastic such as Polyvinyl chloride (PVC) or Isobutylene Isoprene Rubber (IIR). PVC is a popular material but has a short lifespan. IIR is a synthetic rubber, a copolymer of isobutylene with isoprene. It is more durable than PVC but also more expensive.

The lifespan of biogas bag depends on the material of the bag. It should be perfectly sealed. Leakage may occur at the connection parts or when a pin hole is made by puncture or abrasion. It is necessary to conduct periodic checks of connecting parts, pipes and sealing to ensure that there is no leakage.

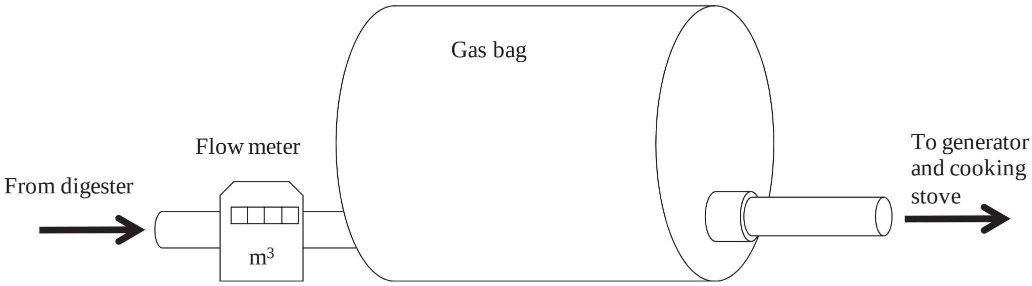


Figure 2.3.1 Concept of Biogas Bag

2.4 Biogas Filter

Biogas contains hazardous and corrosive hydrogen sulfide. Hydrogen sulfide deteriorates metal parts of engines by corrosion and increases maintenance cost. The removal of hydrogen sulfide is very important for sustainable operation of the biogas system.

To remove hydrogen sulfide, a biogas filter needs to be applied. There are two types of biogas filters: activated carbon filter and steel wool filter.

(1) Steel wool type filter

Steel wool type filter is applied in small biogas systems with digesters of up to about 20 m^3. These are typically installed in small digesters. The cost of purchasing a steel wool filter is low, but it needs periodic checking and replacement of steel wool. Initially, the color of steel wool is gray. When the color changes to black, this indicates that it needs replacement. Weekly checks are necessary to confirm the status of steel wool. Steel wool can be found in at kitchen cleaners/scrubbers sections of general stores or supermarkets.


Photos Steel Wool Type Biogas Filter

(2) Activated carbon filter

(3) Activated carbon filter is generally provided by the biogas engine generator supplier. It has a filtering unit with activated carbon pellet. This type has longer lifespan of several years but also requires periodic checking. Activated carbon filter is applied in larger biogas systems than steel wool type.


Photos Biogas Filter and Activated Carbon Pellets

2.5 Biogas Engine and Generator

Biogas is applied for electricity generation. Depending on the size of the biogas generation system, different types of engine generators can be applied.

(1) Small Petro-engine Generator

For smaller biogas generation systems, petro-engine generator is applied for 1-5 kW range. Integrated type gen-set is available in the market. Petro-engine or diesel engine may be connected with alternator, but both need modification to apply biogas. To monitor electric energy output, it is necessary to attach additional voltage and ampere meters.

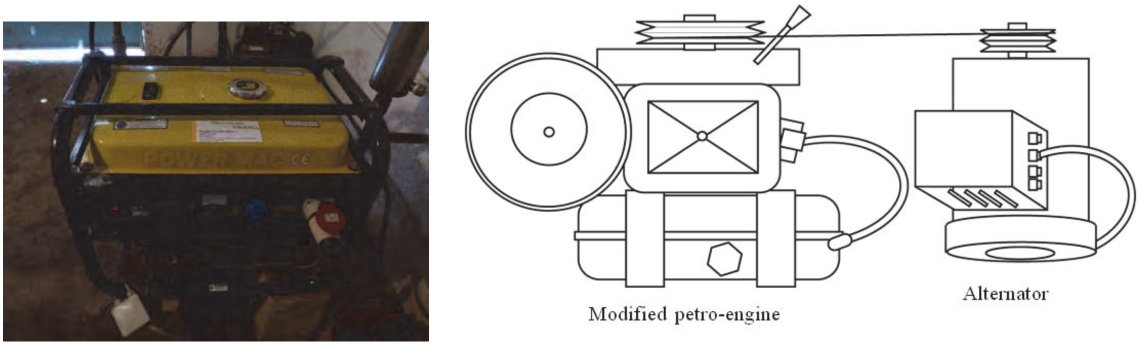


Figure 2.5.1 Integrated Gen-set (Right) and Belt-connected Petro-Engine and Generator (Left)

(2) Biogas Generator

For larger systems more than 10 kW, biogas engine-generators are available and can generally be imported from China, India, Vietnam, etc. Biogas engine-generator is manufactured by modification of a general diesel engine or gas engine. Detail specifications vary depending on the manufacturer. Generally, a display panel is attached to monitor voltage, ampere, power factor, and output.

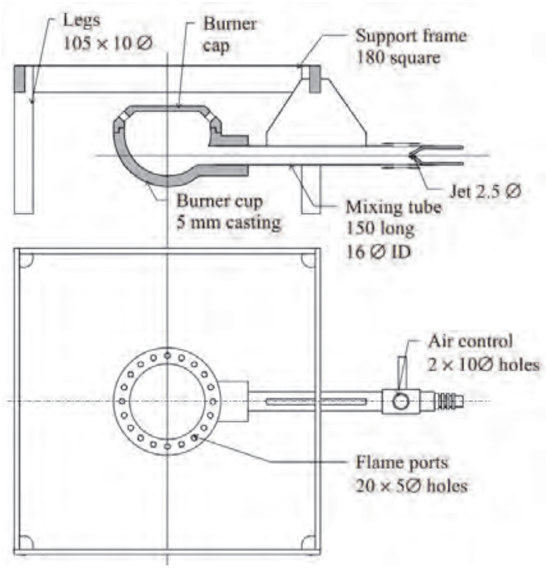
For larger systems (more than 100 kW), heat recovery-heat exchanger can be installed to increase efficiency.

Dual-fuel type of generator may also be installed, to apply other fuels such as diesel oil in addition to biogas.

Photos Biogas Generator and Control Panel

2.6 Biogas Stove

The major application of biogas is cooking. General cooking stoves using LPG, natural gas etc., cannot be used with biogas because it has a different calorific value and air ratio. It is therefore necessary to modify general cooking stoves, specifically to change air flow rate. Biogas stoves are available in the Kenyan market.



Source: Biogas Stove Design, David Fulford, 1996

Photo was taken in Nyongara Slaughter House

Figure 2.6.1 Structure of Biogas Cooking Stove

CHAPTER 3 OPERATION AND MAINTENANCE

Biogas systems are NOT maintenance free. The system requires manpower and proper work for feedstock input and utilization of output. Unless adequate maintenance work is done, the system would have been installed in vain. Users need to participate in operation and maintenance training during construction and commissioning. The training should be provided by the supplier.

3.1 Starting of Biogas Digester

3.1.1 Starting Cow Dung Digester

Biogas digester needs a large quantity of cow dung to be fed into it at the time of starting. One to two months are required from the start of feeding, for methane production to start. The following are general requirements for starting biogas digester:

1) Start collecting and storing cow dung during the construction period or even before.
2) The stored cow dung should be kept covered to avoid drying. Collecting and preserving the cow dung in a pit or under shade with a cover is recommended.
3) If possible, obtain slurry from other existing digester. It contains methane producing bacteria consortium, which can accelerate biogas production when starting. The slurry should be stored in a sealed container and strictly kept from exposure to air during transportation.
4) Strictly avoid pesticide sprays, antibiotics, and other sterilizing agents getting into and mixing with cow dung.
5) When cow dung is collected from outside the facility, make sure it is free from components indicated in 4) above.
6) Make sure that cow shed is modified so that automatic transportation of cow dung and urine is possible by gravity. A ditch is necessary to channel and transport feedstock by gravity. Make sure the elevation of ditches between the cow shed and digester allows flow downstream from the cow shed towards the digester. If not, modification work is necessary.

7) In addition to 6), make sure biogas slurry can be supplied to the garden by gravity. The location of the garden should be at lower elevation than expansion chamber of digester. A ditch connecting digester expansion chamber to the garden, with a gate along the channel is necessary.

3.1.2 Starting Toilet Digester

Preparation of an additional toilet that is not connected to digester is necessary for use by people ingesting antibiotics.

User education is necessary for the following:

✧ Detergents with bacteria disinfection components such as chlorine must not be used to clean toilets connected to digester. Bacteria disinfecting agents in detergents will kill bacteria in the digester. Use detergent without disinfection and antiseptic agents and apply alcohol for sterilization instead.

✧ Do not let people who are ingesting antibiotics use toilets connected to digester. Antibiotic component in human waste of people ingesting antibiotics will kill bacteria in the digester. Ensure that people ingesting antibiotics use a separate toilet not connected to digester.

✧ DO not let anything other than human waste into the toilets connected to digester. Never let sanitary waste or plastic in toilet connected with digester. Waste other than feed stock, especially non-biodegradable material such as sanitary waste and plastic material will remain in the digester and may clog the digester and pipe.

3.2 Daily Routine Works of Biogas Digester

The required daily work items for cow dung digester is as follows.

- Start daily feeding with the amount collected in the cow shed.
- It could take up to 40 days or longer to fill the plant completely (depending on amount of cow dung available)
- Biogas production will start after supply of cow dung and sealing of the plant. Be careful not to have any leakage.
- Daily feeding of the biogas plant is a must.
- Cow dung needs to be mixed with urine/water in the ratio 1:1 before feeding the biogas plant. If 100 kg of cow dung is fed, 100 kg of urine/water should be mixed in.

Figure 3.2.1 Manual Mixing

- Where mixing handle is attached to biogas digester, mix slurry every day (AKUT type digester does not require mixing).
- Sort out straw and wasted fodder so that those do not enter digester.

- Any stalks, straw, stones, sand, etc., must not enter digester. Stalks and straw are difficult to degrade and cause formation of scum in the digester. Stones and sand will accumulate as sediment in the digester and reduce available volume of digester.
- When scum is formed in digester, it will prevent gas flow to the gas outlet. When gas amount is reduced, open the manhole of digester, and check if scum is formed. If scum is seen, remove it.
- Mix cow dung with urine and/or water in the ratio of 1:1. One volume of cow dung to one volume of urine/water. If the urine is not enough, add water to the mixture. The following is an example of urine excretion amount per cow.

Table 3.2.1 Urine Volume per Cow

Item	Dry cow	Lactating cow
Body weight (kg)	612 ±70	614 ±47
Water intake (kg/day)	28.0 ± 9.1	98.4 ±14.9
Urine amount (kg/day)	10.8 ±4.9	21.9 ±7.5

S. Kume, et al, Evaluation of Urinary Nitrogen Excretion from Plasma Urea Nitrogen in Dry and Lactating Cows (2008) Asian-Aust. J. Anim. Sci.Vol. 21, No. 8 : 1159 - 1163

- The amount of urine varies depending on the cow type, cow body weight, and water intake amount, as shown in the table above. When water is not easily available for cows, the urine amount may be about 10 kg/day. When cow dung amount is 30 kg/day for cows in dry lands, water needs to be added and mixed at 20 kg/day per cow (urine 10 kg/day, water 20 kg/day, cow dung 30 kg/day per cow)
- If the digester has a lid, the sealing of the lid must stay moist. The space above the lid must therefore always be fully and completely covered by water. This water jacket should be made and maintained. Pour some heavy oil (this should not be light oil such as gasoline, kerosene, or diesel oil) or waste vegetable oil on top of the water on the lid to reduce water evaporation and to avoid breeding mosquitoes.

3.3 Periodic Works

(1) Checking filter

In case steel wool type filter is applied in small biogas system, check the status of filter weekly.

In case activated carbon filter is applied in larger biogas system, check the pellet once a month for deterioration. Request the supplier to change pellet if deterioration is found.

(2) Checking of slurry pH

Check pH of slurry. If biogas digester is in good condition, the pH of slurry is 6.8 - 7.6. If the condition is acidified (less than pH 6.0), fermentation condition is not good. Feedstock input condition also needs to be reconsidered.

(3) Checking of gas pipe line and removal of moisture

For gas pipeline, collect the condensed water of the moisture remover and remove it. The piping must have a slope and be fitted with water traps at the lowest point along the piping. Each water trap has its own covered manhole. The water trap automatically allows the overflow of excess water.

3.4 Expansion Chamber and Effluent Use

Effluent, or biogas slurry, is a good fertilizer and can be used on vegetables, feeds, and other plants. Its economic value is very high.

Another potential use of the effluent is as animal feed. If the effluent is dewatered, the resulting cake may be used as animal fodder.

- Overflow pipe or point of entry into expansion chamber, as well as the slurry channels should not be clogged. Regular checks should be done to ensure the flow and distribution of slurry to the garden is unimpeded.

Photo Biogas Slurry from Small Digester and Large Digester

- Put a grill cover over the expansion chamber to prevent accidental falls.

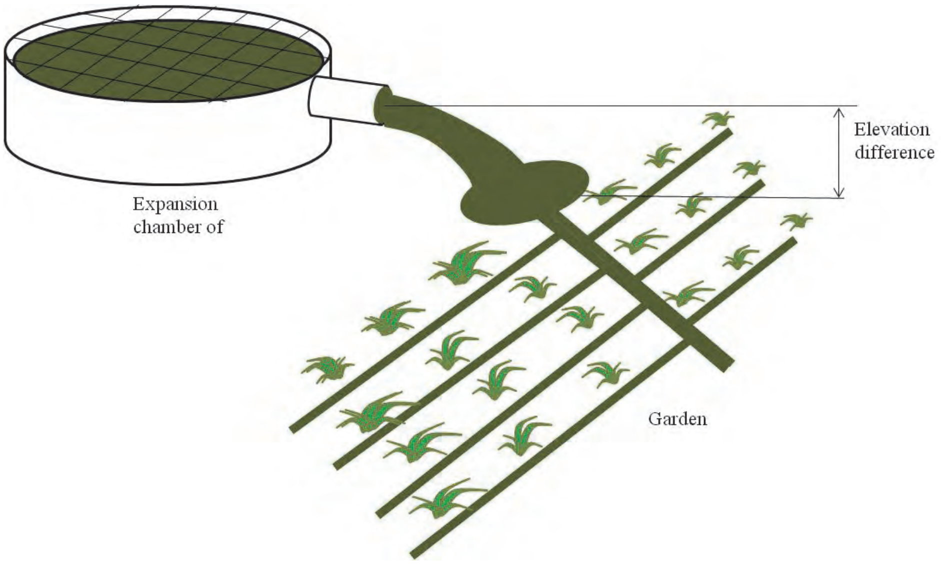


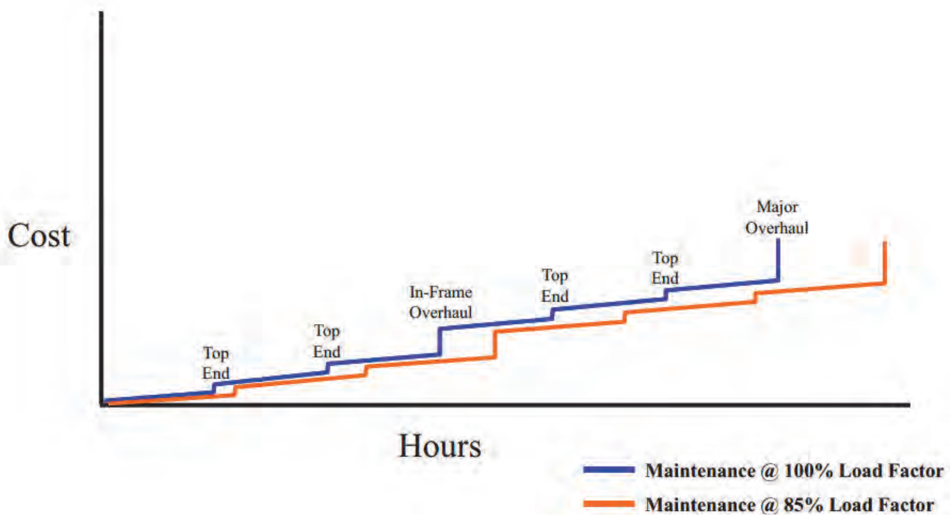
Figure 3.4.1 Utilization of Biogas Slurry as Fertilizer in Garden

Make sure that the garden is apart from wells collecting ground water. Contamination of surface and groundwater due to disposal of biogas slurry: pathogens (in case of toilet connected digester), particulate matter and COD/BOD should be avoided.

3.5 Operation and Maintenance of Engine and Generator

Since biogas engine generator includes mechanical motive parts much like a car engine, it requires periodic maintenance. The maintenance requirement of biogas engine generator consists of preventive maintenance, scheduled maintenance, and unplanned repairs.

The following figure is the concept of maintenance requirement. Every 5-8 years, engine requires overhaul.



Source: Maximizing Productivity of Biogas Engines, Seventh AgSTAR National Conference (2013), Catarpillar

Figure 3.5.1 Concept of Relation of Cost and Operation Hours

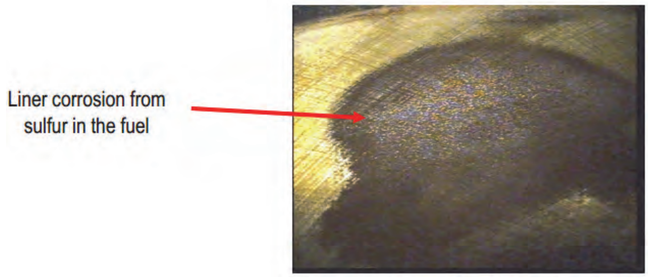
Preventive maintenance can reduce requirement of scheduled maintenance and occurrence of unplanned repairs.

Predictive maintenance can be conducted with following works:

- Monitor all aspects of engine operation (valve recession, oil consumption, fuel consumption, exhaust gas temperature, emissions, etc.
- Monitor wear trends
- Repair before failure

The user should develop a long term strategy for engine-generator maintenance. It is suggested that predictive repair scheduling can reduce O&M cost by up to 15%.

Biogas contains corrosive and contaminant components, that is, sulfur compounds and acids. Hydrogen sulfide (H_2S) forms sulfuric acid, and metals containing copper are corroded by sulfuric acid.



Source: Maximizing Productivity of Biogas Engines, Seventh AgSTAR National Conference (2013), Catarpillar

Figure 3.5.2 Corrosion by Sulfur on Metal Surface

Proper filtering of biogas is necessary to remove contaminants. Especially for an engine-generator system, activated carbon filter needs to be installed and maintained by replacing the pellet at certain intervals. Removal of contaminants will lead to the following merits:

- Extended engine overhaul intervals
- Longer spark plug lifespan
- Extended oil change intervals
- Better lifespan of components
- Lower overall maintenance costs

All Manufacturers should have guidelines for maximum fuel contamination, and these should be requested and confirmed by the engine supplier.

For larger systems, it is recommended to have a long-term maintenance contract with the engine supplier.

3.6 Biogas Cooking Stove

The following are the operation and maintenance items for biogas cooking stove:

- Regularly maintain and clean all gas consumption accessories, manometer, pipe, and cooking stove.
- Cooker should be cleaned every day. Clogging of pipes will reduce power. Replace mantles when torn or worn out
- Close related valves when appliances are not in use

It is necessary for users to know how much biogas is available for use in cooking stove. It is possible to know the biogas amount available, by using gas pressure. A manometer should be installed to know gas pressure. If there is no manometer, to measure gas pressure, a simple manometer can be installed by connecting a U-shaped piece of transparent hose filled with water. This is used to measure pressure of the gas line.

The U-shape of a hose should have a height of at least 30 cm (total length should be more than 1m), and the water level should be approx 10-15 cm from the bottom. As pressure builds up, the water level in one of the two legs will drop, and increase in the other. The pressure (in mbar or cm water) is equal to the height difference of the water levels in the two legs of the hose.

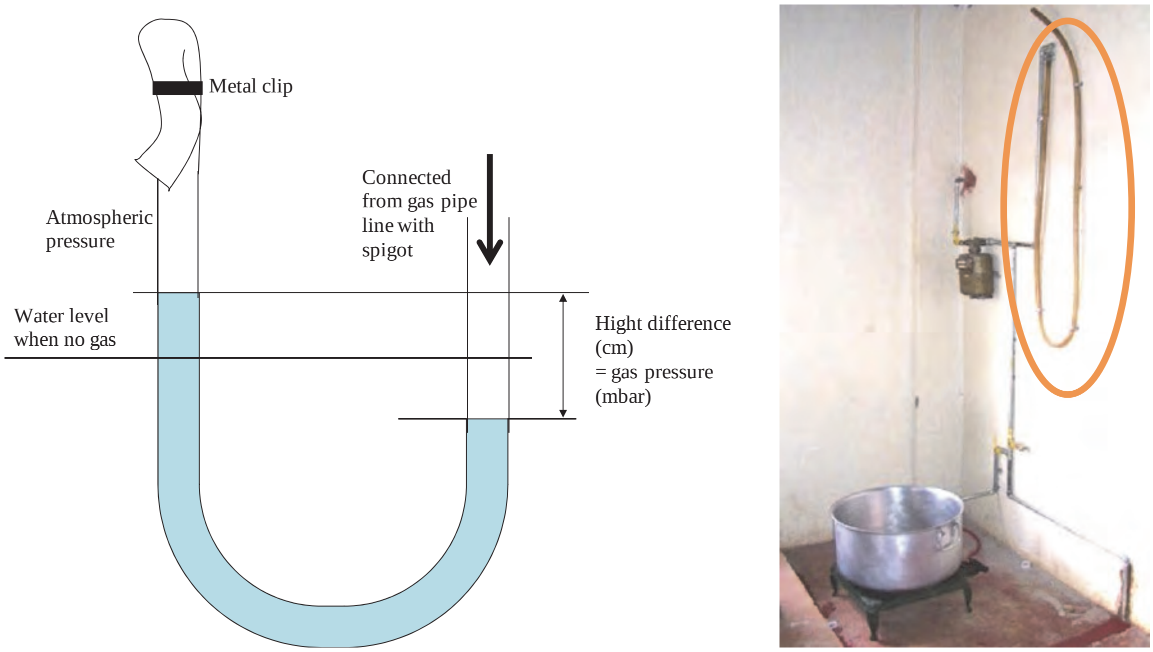


Photo: http://ecosankenya.blogspot.com/2010/12/status-gachoire-girls-high-school.html

Figure 3.6.1 Manometer Concept and Gas Pressure Measurement

The water in the manometer will be lost by evaporation. It is necessary to add water once in a while to ensure that the manometer shows the correct plant pressure. To refill water, close the main valve at the biogas digester, and open the valve at the cooker. The manometer should now show a reading of “0”. If it is less than “0”, add water carefully until it shows “0”. Then, close the cooker valve and reopen the main valve.

Manometer with an analogue indicator is also available, as shown in the picture below. The gas pressure and gas production amount is shown in the table below.

Table 3.6.2 Gas Pressure and Gas Production Amount

Digestor Size m^3	Dung/day kg	Nos of Cow	Gas production m^3	Max Pressure (cm) (mbar)
8	100	5	3	94
12	150	7	4.5	97
16	200	9	6	105
24	300	13	9	115
32	400	17	12	125
48	600	25	18	125
59	740	31	22	127
71	900	38	28	133
80	1100	46	34	135
124	1500	63	46	140

Source (table): Modified by WG from Biogas Construction Manual (2011), GIZ, GmbH, and PSDA
Source (photo): Appliance for Domestic Biogas Plants, Biogas compact course PPRE- Oldenburg University (2011)

CHAPTER 4 RECORDING

4.1 Recording of Produced Gas

Produced gas amount is indicated by gas flow meter. Check gas flow meter reading every day and record it. If several digesters and gas flow meters are installed, check and record the reading of each digester's meter and calculate total amount of biogas.

Gas flow meter reading at biogas bag should also be recorded. Generally, the amount of gas flow at biogas bag is almost the same as the total amount of biogas amount from digesters.

Table 4.1.1 Recording Form of Biogas Production Amount

Date	Day	Time	Gas Production				
			Digester-1	Digester-2	Digester-3	Gas Bag	Daily
			m^3	m^3	m^3	m^3	m^3
1							
2							
3							
4							
5							

If there is an obvious difference in these two amounts, gas leakage along gas pipeline is involved and should be checked.

The production amount will depend on conditions such as temperature and feedstock input into the digester. If there is obvious change in biogas quantities without any corresponding changes in conditions, leakage or other problems are involved. Check pipe line, pH of biogas, and condition of toilets and cowshed, and scum formation inside the digester to determine if antibiotics or bacteria sterilizing detergent are used.

4.2 Recording of Generated Energy

For the generated energy using biogas, the user needs to record date, generation hours, gas quantity that was used for generation (m^3), generated energy amount (kWh), maximum load (kW), frequency of generator, and speed and temperature of engine. These are important indicators to inform maintenance personnel about efficiency, requirement of checkup and repair, and other operation conditions.

The following table is an example of recording sheet for biogas generation.

Table 4.2.1 Recording Sheet of Biogas Generation

Date	Generation Hours			Gas (m^3)			Eenrgy (kWh)			Max load	Frequency (Hz)		Speed (rpm)		Temperature (℃)	
	Start	Finish	Hours	Start	Finish	Balance	Start	Finish	Balance	(kW)	Max	Min	Max	Min	Max	Min

Monitor the total operation hours. This will be the indication for the need to conduct repairs. Follow manufacturer's instructions to determine the requirement of repairs at a particular number of operation hours. For example, in-frame overhaul is required after 8,000 hours of operation.

4.3 Recording of Maintenance and Repair

Maintenance record should be made each time for repair and maintenance works. The record is Maintenance records should be made and kept each time repair and maintenance works are undertaken. The record is important and should be used to prepare annual maintenance plan for operation. It should also be kept for annual budgeting and accounting in the facility.

The information should include date, name of operator in charge, name of manager, items for maintenance (engine, generator, filter, gas bag, pipe line, valve, digester, etc.). The problem and cause, work component for maintenance and repair, required repair and replacement items and their costs, and total cost of the session should be recorded. The following is an example of maintenance record form. This should be modified according to system components and requirement of maintenance works.

Table 4.3.1 Maintenance and Repair Record Form

Maintenance Record

Date/Month/Year: ______________ Location: ______________

Operator Name ______________ Approved by: ______________

Maintenance Item: Engine / Generator / Filter / Gas Bag / Pipe / Valve / Digester / Other ( )

Problem : ______________

Maintenance and repair work component: ______________

Cause of problem and prevention method: ______________

Required items for repair and replacement and its cost, if any: ______________

Total Approximate Cost: ______________ Ksh

CHAPTER 5 SAFETY

5.1 General

Users should be sufficiently aware that biogas is flammable due to methane content and toxic due to hydrogen sulfide content.
The location where gas bag and biogas engine are installed must be well ventilated. Warning signs with the following items should be provided near biogas digester, gas bag and generation house:

- **Biogas is explosive when it comes into contact with air. NEVER smoke, or light a match or fire near biogas digester, pipe, gas bag, and generator!!**
- **Note that biogas is also produced during the filling process.**
- **Fire extinguishers and warning signs must be attached in power house.**

Photo Fire Extinguisher and Warning Sign

5.2 Methane Gas

There is a danger of poisoning due to biogas. Hydrogen sulfide contained in biogas is highly poisonous.

Special care should be taken not to inhale biogas during mixing of feedstock and exchanging of the activated carbon filter used for gas cleaning.

When there is excess biogas, never release it into the air. Use it by boiling water with cooking stove or other methods.

Note that methane gas has as much as 20 times more effect on global warming as CO_2. It should therefore not be released into the air in order to mitigate global warming.

5.3 Hydrogen Sulfide

Hydrogen sulfide, H_2S, is hazardous. Generally, the concentration of H_2S in biogas is 500 ppm-10,000 ppm. The leakage of biogas must therefore be strictly prevented or reduced.

If any leakage occurs in a closed room, open windows for ventilation, wear masks and conduct repair work.

5.4 Effluent

(1) Effluent from cow dung digester

In the case of effluent from cow dung digester, there is no concern over the safety of effluent. It can be fully utilized as fertilizer and soil improvement material for gardens. However, it should not be used near wells and groundwater locations, since it will increase COD/BOD and affect water quality.

(2) Effluent from digester connected to toilet

In the case of effluent from toilet connected digester, the effluent may contain helminth eggs or coliform. It can therefore be utilized as fertilizer only when appropriate and adequate care is taken. The system operator should wear protective gear such as gloves and boots. Vegetables growing in the areas where the effluent is flowing should not be eaten raw.

It is advised not to use effluent of toilet connected digester, but instead to connect the expansion chamber to an existing septic tank by a ditch or pipe.

CHAPTER 6 OPERATION DOS AND DON'T

6.1 "DO" Items

The following table summarizes "DO" items for biogas operation and maintenance.

Table 6.1.1 "DOs" for Biogas Operation and Maintenance

Item	Description	Frequency
KEEP FIRE AWAY!	Biogas is explosive. Put up signs of "keep fire away", and never smoke cigarettes or use other fire related objects near digester, gas pipe line, and power house.	Every day, every time
Check overflow and slurry ditch to ensure it is free from clogging. Remove any obstacles in the path of slurry.	Overflow pipe or point of entry into expansion chamber as well as the slurry channels should not be blocked. Regular checks should be done to ensure the flow and distribution of slurry to the garden is unimpeded.	Every day
Check if biogas filter has deteriorated.	Steel wool filter deteriorates rapidly. When gray color of steel wool changes to black, it should be replaced. In the case of activated carbon filter, check the pellet occasionally.	Steel wool filter: Once in a week. Activated carbon filter: Once in 2-3 months
Check pipeline and bas bag to ensure there is no leakage.	If there is any leakage, not only is it a loss of energy, but it also possess fire and explosion hazards. Leakage should be strictly avoided.	Occasionally

Item	Description	Frequency
Remove condensed water in pipe line.	For pipeline, collect the condensed water of the moisture remover and remove it. The piping must have a slope and be fitted with water traps at the lowest point along the piping. Each water trap has its own covered manhole. The water trap automatically allows the overflow of excess water.	Weekly
Proper treatment of excess biogas	When biogas bag is inflated and there is excess biogas, never release it into the air. Use it by boiling water with cooking stove or other methods.	When required
Check overflow and slurry ditch to ensure it is free from clogging. Remove any obstacles in the path of slurry flow.	Overflow pipe or point of entry into expansion chamber as well as slurry channels should not be blocked. Regular checks should be done to ensure the flow and distribution of slurry to the garden is unimpeded.	Every day
Check gas flow meter and record production amount.	Gas production amount needs to be recorded every day to assess the condition of biogas digester.	Every day

6.2 "Don't" Items

The following table summarizes "DON'T" items for biogas operation and maintenance.

Table 6.2.1 "DON'Ts" for Biogas Operation and Maintenance

Item	Description
DO NOT inhale leaked biogas.	There is a danger of poisoning due to biogas. Hydrogen sulfide contained in biogas is poisonous. Special care should be taken not to inhale biogas when mixing feedstock and exchanging the activated carbon filter used for gas cleaning.
DO NOT use biogas slurry near a well that collects ground water.	Make sure that the garden is located at a distance from wells collecting ground water. Contamination of surface and groundwater due to disposal of biogas slurry: pathogens (in the case of toilet connected digester), particulate matter, COD/BOD should be avoided.
For cow dung digester	
DO NOT store feedstock unused for a long time. Use produced feedstock (cow dung) as soon as possible.	Wet feedstock emits more methane during storage than dry feedstock. When methane is produced, it possess a fire hazard. In addition, methane contributes more to global warming than CO_2.
DO NOT let stalks, straw, stones and sand into digester.	A digester must be free of stalks/straw and inorganic materials such as stones or sand as they cause sediment and scum inside the digester. These are not biodegradable and should be avoided.
DO NOT use pesticides and antibiotics for the cows and cow shed.	If it is unavoidable for such agents to be applied, strictly avoid using them in the cow shed. Further, avoid antibiotics and other sterilizing agents mixing in cow dung. Note that antibiotics fed to cows remain in cow dung.
For toilets connected to digester	
DO NOT use detergents with	Bacteria disinfection agents in detergents will kill bacteria in the

Item	Description
bacteria disinfection agents such as chlorine to clean the toilets connected to digester	digester. Use detergents without disinfection and antiseptic agents and apply alcohol for sterilization instead.
DO NOT let people who are ingesting antibiotics use toilets connected to digester.	Antibiotic component in human waste of people ingesting antibiotics will kill bacteria in the digester. Ensure that people ingesting antibiotics use a separate toilet not connected to digester.
DO NOT let anything other than human waste into the toilets connected to digester. NEVER let sanitary waste or plastic in toilets connected to digester.	Waste other than feed stock, especially non-biodegradable material such as sanitary waste and plastic will remain in the digester and may clog the digester and pipe.
NEVER use any sharp objects to remove blockages in the inlets and outlets of gas bag.	This can easily lead to punctures in the bags or breaking of pipes.

6.3 Trouble Shooting

The following table summarizes trouble shooting items for biogas operation and maintenance.

Table 6.3.1 Trouble Shooting for Biogas Operation and Maintenance

S#	Phenomena	Description
P-1	Gas is produced after start up, but it is not flammable.	The flammable component in biogas is methane, which is not produced immediately after start up. It will take time for methane content to build and for the gas to become flammable. The gas that is produced for one month after start up mainly consists of carbon dioxide (CO_2). Wait for a few days after this milestone until methane content builds up to the level of biogas.
P-2	There was gas after start - up, but it stopped	The bacteria inside the digester may have died due to high acidity, antibiotics, or poison. Flush out the digester contents twice with a large amount of water and start it again.
P-3	There is gas, but it flows very slowly	The gas pipe may be blocked. Check the pressure of the gas. Check the gas pipe system for blockages.
P-4	There is gas, but the supply is too little to meet daily energy needs	1) Check if you feed it enough. 2) Check if there is leakage in gas pipe line and gas bag. 3) Check if antibiotics and bacteria sterilizing agents are used in cow shed and toilet. If these are used, stop their use as they kill the bacteria which are necessary for methane fermentation. Gas production can also be increased by adding co - substrate. Discuss with an expert to determine which types may be appropriate for you. 4) Check if scum is formed in the digester. Open the manhole of the digester, and if scum is formed, remove it.
P-5	There is no gas production.	Check the items as listed in P-4 above. Check if the feedstock input amount is as planned, relative to the digester volume. If there is no leakage, check pH value. If pH is lower than 6.0, the substrate inside the digester is acidified. Flush out the contents of the digester with a large amount of water twice, then, start it again.
P-6	Manometer does not work properly.	Check if water is lost by evaporation. See Chapter 3.5 for refilling water.

GUIDELINE FOR BIOGAS GENERATION

PART-III
GUIDELINE FOR MONITORING AND EVALUATION

PART-III GUIDELINE FOR MONITORING AND EVALUATION

CHAPTER 1 MONITORING

1.1 Necessity of Recording and Monitoring

There are two types of monitoring; daily monitoring conducted by the operator and occasional monitoring conducted for purposes of problem solving and operation improvement.

Monitoring is necessary for project evaluation, extraction of lessons learned, and feedback to other similar projects. Without proper recording, meaningful data cannot be obtained. Training of users on how to conduct proper recording is necessary, and should be undertaken during commissioning phase.

Recording is done as part of daily operation by operators of the biogas system. Monitoring is done by the supervisor who is responsible for reporting or the public institution in charge of the project. Monitoring is conduced mostly for the purpose of evaluation.

1.2 Monitoring Item

The necessary items for monitoring biogas system are summarized in the following table.

Table 1.2.1 Monitoring Items

Item	Unit	Description	Frequency
Biogas Production amount	m^3	Biogas production amount. Measured by gas flow meter.	Every day
Generated Energy	kWh	Energy amount generated by biogas generator. Measured by energy meter.	Every day
Energy Output	kW	Power output by biogas generator. Measured by biogas generator indication.	Every day
Temperature	^oC	Ambient temperature. Complementary information to assess gas production efficiency.	Every day
pH	-	Potential of hydrogen. This is the indication of acidity and alkalinity condition inside a biogas digester and slurry. Optimal pH is 7-8.5.	Occasional monitoring
Methane concentration	%	Percentage of Methane in biogas. This is the indication of biogas production.	Occasional monitoring
ORP	mV	Oxidation Redox Potential. This is the indication of anaerobic condition of biogas digester.	Occasional monitoring
Biogas analysis (detailed)	-	Gas is sampled and sent to a laboratory. Concentration of components is analyzed by gas chromatography (Generally CH_4, CO_2, O_2, N_2, H_2. etc.)	When required for study and R&D purpose

The recording and monitoring items and its frequency are as follows:

(1) Biogas production amount : daily by operator

Gas production amount can be measured by a gas flow meter. It is important to record daily gas production amount by reading the gas flow meter for the following purposes:

- To check whether the digester condition is appropriate for proper gas production
- To assess efficiency of gas for generation and cooking fuel
- To check gas leakage
- To obtain information about seasonal fluctuation according to temperature change

The followings are the remarks on gas flow meter.

- Gas flow meter should be attached to each biogas digester and assembled point
- The biogas is corrosive due to H_2S component and will cause deterioration of the gas flow meter. The gas meter needs to be replaced when corroded, to maintain proper recording function.

(2) Generated Energy : daily by operator

In addition to biogas production, generated energy amount is a key basic indicator for monitoring and evaluation. Generated energy needs to be recorded in order to assess the level of reduction in the amount of electricity purchased from the power company.

When generator is installed, generated energy needs to be measured by energy meter. Energy meter indicates accumulated electric energy generated by biogas generator. The energy meter is installed as an Annex to engine and generator. The amount of kWh indicated on the energy meter should be recorded twice every day, at the start of operation and at the end of operation.

(3) Energy Output: daily or occasionally by operator

Energy output provides reference data about actual power output generated by the generator. When power indicator is installed in a generator, the display will indicate the power output. Otherwise, when ampere meter and voltage meter are installed, power can be calculated using the following formula, in the case of a three-phase AC generator:

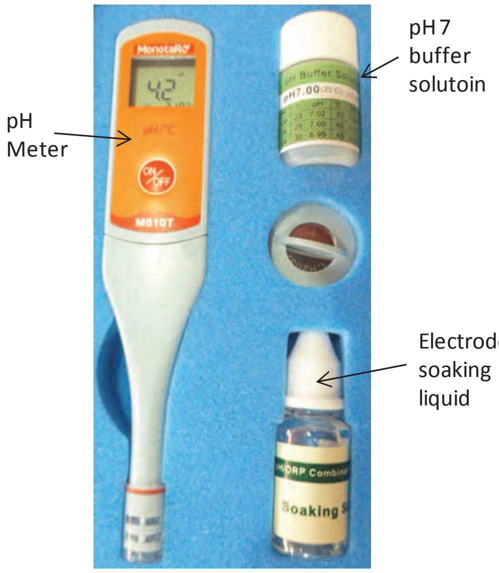
$P = V \times A \times \cos\theta$,

Where, V: Voltage (V),

A: Ampere (A),

$\cos\theta$: power factor

(4) Temperature : daily by operator



Ambient temperature is referred to assess biogas fermentation condition. Biogas producing bacteria are active when temperature is high and vise versa. Retention time is affected by temperature.

(5) pH: occasionally at monitoring

pH value of slurry indicates condition inside the biogas digester. When methane is not produced up to the expected amount or at all, pH value needs to be checked. For methane fermentation, the optimal pH value is 6.8-7.6. When pH of slurry becomes too low (below 6.0), intermediate metabolite of organic acid is accumulated and the condition in the digester is acidified. Then, methane production is considered not to be ideal. At this time, acidic intermediate metabolite is produced and accumulated, and further degradation processes which are necessary for methane production will not occur as expected. When pH is determined to be a problem, the feedstock type and feeding condition need to be reconsidered.

(6) Methane concentration: occasional monitoring

Percentage of methane in biogas indicates the status of biogas production. With portable methane detector, it is possible to measure high concentration methane by measuring thermal conductivity. Using a suction pipe and gas sampling hose, biogas from pipe outlet in a system is sucked into the detector. Methane detector has accuracy level of ±5-10%, and the concentration value indicated is not very accurate. To measure precise methane percentage, gas chromatography analysis is necessary.

(7) ORP: occasional monitoring

ORP meter measures oxidation and reduction potential (ORP). ORP is the indication of the extent of anaerobic condition in the biogas digester. Anaerobic digestion requires negative ORP. ORP is indicated with Eh value (mV). If ORP is positive, leakage may occur or feedstock may not be appropriate. The aerobic/anaerobic condition and corresponding Eh value is shown in the table below.

Table 1.2.2 Anaerobic Condition and Eh Value

Aerobic Condition	Eh (mV)
Aerobic respiration	>+330
Denitrification	+330 to 220
Manganese reduction	+220- 200
Ion reduction	+200 to 120
Sulfate reduction	+120 to – 150
Methane production	-150 -250

(8) Gas chromatography: for R&D purposes

Gas chromatography is a method of gas analysis. Chromatography is used to separate a mixture of gas and to analyze compounds that can be vaporized without decomposition. Gas chromatography can separate different types of gases by the absorption characteristics of each type of gas, in a long column. Gas chromatography identifies the type of gas and its concentration, by making a comparison to a standard gas. To accurately measure concentration of methane gas and biogas composition, it is necessary to request a chemical laboratory to conduct gas chromatography analysis.

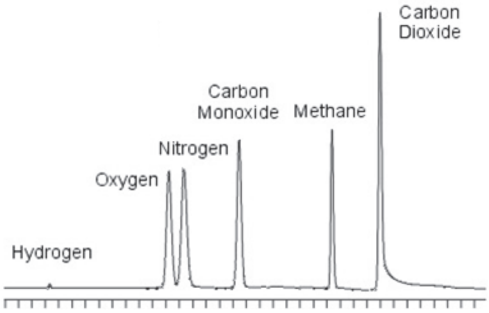


Figure 1.2.1 Example of Chromatogram of a Gas Mixture

The following items can be analyzed by gas chromatography of biogas:

- CH_4
- CO_2, CO, H_2, O_2, and N_2

By analyzing the respective percentages of the above gases, calorific value of biogas can be calculated.

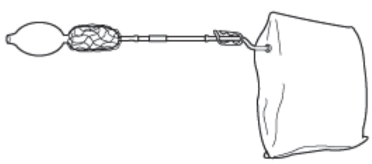
Sampling of biogas for analysis should be conducted using a special sampling gas bag. The sampling bag should have following characteristics:

- The sampling bag should be a product specifically for gas-chromatography sampling
- The material of the sampling bag should be made of synthetic resin film such as vinyl alcohol polymer, Poly Vinylidene DiFluoride (PVDF), or Polyvinyl fluoride (PVF).
- The sampling bag should have a sleeve for inlet and be perfectly sealed

The sampling procedure should be conducted as follows:

- Make a reservation at a laboratory with gas chromatography, to confirm for sample gas submission before sampling
- To sample, use a hose pipe from the gas outlet with taping to create a seal so that ambient air contamination is minimized
- Repeat biogas filling and emptying out of the gas bag three times, and then fill the biogas sample
- Within six hours, submit the gas sample to the laboratory. Since leakage cannot be avoided, the earliest possible submission to the laboratory is the best.

The figures indicated below are an example of gas sampling bag.



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(9) Calorific Value of Biogas

From the analysis result of biogas, actual calorific value of biogas can be calculated. The gas components that contribute to the calorific value of biogas are methane and hydrogen. From calorific value (mol/Nm^3) and the gas constant of 24.8 L/mol, the calorific value of each gas component can be calculated using the following formula.

$$C_{biogas} = \sum_{i} \frac{r \times C_i}{24.8} \times 1000$$

Where, C_{biogas}: Calorific value of biogas (MJ/m^3)
r: Percentage of respective gas (i) component
C_i: Calorific value of gas (i) (MJ/m^3)

The table below shows an example of biogas analysis results and calculation of calorific value.

Table 1.2.3 Example of Biogas Analysis and Calorific Value

Type of Gas		%	MJ/mol	mol/Nm^3	MJ/Nm^3
Methane	CH_4	60%	0.889	24.19	21.51
Hydrogen	H_2	3%	0.286	1.21	0.35
Carbon dioxide	CO_2	25%	0	10.08	0.00
Nitrogen	N_2	10%	0	4.03	0.00
Hydrogen sulfide	H_2S	2%	0	0.81	0.00
Oxgen	O_2	0%	0	0.00	0.00
TOTAL		100%			21.85

In the above example, the calorific value of biogas was 21.9 MJ/Nm^3, which is about 60% of the calorific value of methane at 36 MJ/Nm^3. It can therefore be considered that the calorific value of biogas is proportional to the concentration of methane.

1.3 Format of Recording and Monitoring

A format for recording and monitoring needs to be prepared and provided at the time of user training. The forms and scope of user training should be included in the bidding document and contract with the contractor. The form of recording and monitoring should include items (1) to (4) in chapter 1.2 for daily recording and (1) to (7) in chapter 1.2 for occasional monitoring.

In public projects, monitoring by the donor or government should be conducted biannually and annually. Necessary data should be collected in the monitoring process and used for project evaluation.

The base format for information collection for monitoring is shown in the figure below. The format can be used together with “Form of Daily Gas Production” and “Energy Data Sheet”, which are the same as those applied for user O&M.

Monitoring Form of Biogas Generation System: Base Information Sheet

Date/Month/Year: ____________ Location: ____________

Operator Name ____________ Approved by: ____________

Monitoring conducted by: ____________

1. Data for Cow Dung Digester:

   Nos of cow (for digester) Mature: ________ Child: ________ Total: ________

   Average amount of dung per cow (20 kg/cow, as standard) ________ kg/cow

2. Data for Digester connected with Toilet:

   Nos of users of toilet connected with digester ____________ Ratio of daily use of toilet connected with digester ________

   Average weight of ratio of users of toilet (user average/adult average) ________

3. Fuel Wood Usage (compare current and before system installation, if possible)

   3.1 Current use of fire wood ________ times/year by truck, wheel-barrow, other
   Truck ________ times/year ________ kSh/time
   Wheel barrow ________ times/year ________ kSh/time
   Other ( ) ________ times/year ________ kSh/time
   3.2 Total use of fuel wood : ________ ton/year (times/year x kg/times as indicated above)

   If possible, obtain following data of the period before biogas system installation for reference:

   3.3 Use of fire wood before system ________ times/year by truck,wheel-barrow, other
   Truck ________ kg/times
   Wheel barrow ________ kg/times
   Other ( ) ________ kg/times
   3.4 Total use of fuel wood : ________ ton/year (times/year x kg/times as indicated above)
   3.5 Difference before and after installation of biogas system (3.4 - 3.2) ________ ton/year
   (This is just a reference value. Actual difference fuel wood saving should be calculated by produced amount of biogas)

4. Electric Energy Usage (obtain electricity bill of Kenya Power from the user)

   4.1 Current electricity payment of the month ________ kSh/month
   4.2 Current electricity usage ________ kWh/month

   If possible, obtain following data of the period before biogas system installation for reference.
   The bill should be the same month of the monitoring.

   4.3 Electricity payment of the same month ________ kSh/month
   4.4 Electricity usage of the same month ________ kWh/month
   4.5 Difference of tariff before and after installation of biogas system (4.3 - 4.1) ________ kSh/month
   4.6 Difference of electric energy before and after installation of biogas system (4.3 - 4.1) ________ kWh/month
   (4.5 and 4.5 are just a reference value. Actual electricity saving should be calculated by the electric meter)

5. Total gas production per month ________ m^3/month
   Gas used for cooking fuel per month ________ m^3/month
   Gas used for energy generation per month ________ m^3/month
6. Total electric energy production per month ________ kWh/month
   (Gas and Electric Energy Data Sheet should be used for 5. and 6. above.)

7. Cost of firewood ________ kSh/ton (calculate from 3.1 and 3.2)
8. Tariff rate ________ kSh/kWh

Figure 1.3.1 An Example of Form for Base Data Collection in Monitoring and Evaluation

Table 1.3.1 Form of Daily Gas Production and Energy Data Sheet

Monitoring Form of Biogas Generation System: Gas and Electric Energy Data Sheet

Year/Month: ______________________ Location: ______________________

Operator Name ______________________ Approved by: ______________________

Date	Day	Time	Gas Production					Generation Data		
			Digester-1	Digester-2	Digester-3	Gas Bag	Daily	Max Power	Energy	Daily
			m^3	m^3	m^3	m^3	m^3	kW	kWh	kWh
1										
2										
3										
4										
5										
6										

(cont.)

Maintenance Record

Date/Month/Year: ______________________ Location: ______________________

Operator Name ______________________ Approved by: ______________________

Maintenance Item: Engine / Generator / Filter / Gas Bag / Pipe / Valve / Digester / Other (   )

Problem : ____

____

Maintenance and repair work component: ____

____

____

____

Cause of problem and prevention method: ____

____

____

Required items for repair and replacement and its cost, if any: ____

____

____

Total Approximate Cost: ______________________ Ksh

Figure 1.3.2 Sample of Maintenance Record Sheet

CHAPTER 2 EVALUATION

2.1 Evaluation

It is necessary to plan monitoring and evaluation activities in the project schedule. Evaluation is conducted mainly by the government or by the donor funding or supporting the project. Evaluation is undertaken for the following purposes:

- To analyze system efficiency
- To obtain lessons and learn from them for implementation of similar projects in future
- To provide advice for better and more efficient operation

Especially for public projects, it is necessary to present data and analysis results to justify the project according to accountability requirements.

The process for evaluation is shown in the figure below.

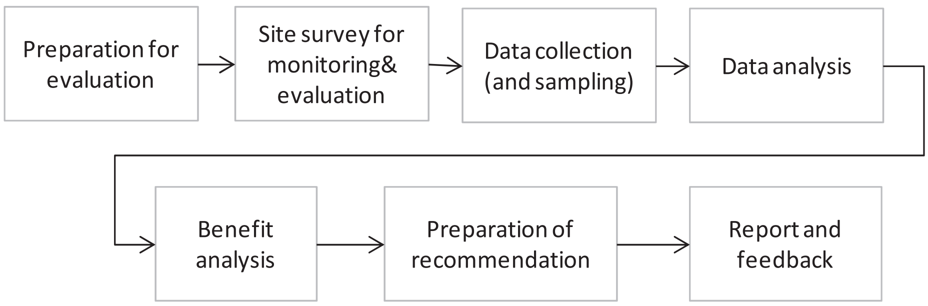

Figure 2.1.1 Flow of Monitoring and Evaluation

The work items for the evaluation are as follows:

(1) Preparation for Evaluation

The preparation includes (i) information to the user about monitoring and obtaining appointment with operator, (ii) preliminary information collection about system condition, (iii) preparation of monitoring and evaluation format for information collection. The format for planning and monitoring as shown in Annex-1 can be used for this evaluation. Based on preliminary information from the user, the form should be modified and adopted. If the monitoring team conducts gas analysis, a gas sampling bag with hose and tape needs to be prepared.

(2) Site survey for monitoring& evaluation

Monitoring and evaluation activities should include a representative of the facility in which the biogas system is installed and the operator in charge of daily operation. Their attendance is necessary for site survey. The survey should collect information on (i) system status, (ii) maintenance record, (iii) feedstock status, (vi) slurry utilization status, and (v) safety status. The monitoring team should check the condition of the system. The items for inspection are shown in table 2.1 that follows in the next page.

(3) Data collection (and sampling)

Data needs to be collected on feedstock input, gas production, electric energy generation and fuel price. The related forms are shown in chapter 1.3.

(4) Data analysis

Data analysis is conducted for information collected at the site on feedstock input, energy generation and gas production. The method is similar to that described in Section 2.2 Technical Evaluation.

(5) Benefit analysis

Based on the results of data collection, data analysis and technical evaluation, benefit analysis is conducted. The detailed method is described in Section 2.3

(6) Preparation of recommendations

Based on findings, recommendations should be made on how to improve operation and maintenance.

(7) Report and feedback

Table 2.1.2 Inspection Sheet for Monitoring

Items	Select	Remarks
1 Biogas digester		
1.1 Are there no leakage from valve?	Yes/No	If yes, valve replacement necessary.
1.2 Does it smell with odor?	Yes/No	If yes, check if there is no leakage.
1.3 Are there no crack on concrete and brick?	Yes/No	If yes, repair is necessary.
1.4 Does the flow meter work well without rust?	Yes/No	If no, meter replacement necessary.
1.5 Check flow rate.	______	m^3
2 Toilet and septic tank (connected with digester)		
2.1 Are there no overflow?	Yes/No	If yes, inform facility to deal with it.
2.2 Are there no odor?	Yes/No	If yes, inform facility to deal with leakage.
2.3 Chlorine detergent and antibiotics are used in toilet?	Yes/No	If yes, instruct facility to prohibit, and tell them it will damage bacteria in digester.
2.4 Extra waste (sanitary waste, paper, etc) flows to digester?	Yes/No	If yes, instruct facility to educate user not to do.
3 Pipeline and manhole		
3.1 Are there no leakage?	Yes/No	If yes, repair is necessary.
3.2 Conduct visual inspection if there is no failure.		
3.3 Conduct sampling of biogas, if necessary. (Note: Keep fire away!)	(for gas analysis)	
4 Gas bag		
4.1 Are there no leakage?	Yes/No	If yes, repair is necessary.
4.2 Does it smell with odor?	Yes/No	If yes, leaked. Check through.
4.3 Are fitting and pipes fine without loose connection?	Yes/No	If no, replace the part.
4.4 Check the accumulated flow.	______	m^3
5 Power house and engine-generator		
5.1 Engine starting and operation no problem?	Yes/No	If no, advise to contact to supplier.
5.2 Check output.	_____	kW, A, V
5.3 Check accumulated energy	______	kWh
5.4 Engine operates without strange noise?	Yes/No	If no, advise to contact to supplier.
5.5 Same failure repeated in maintenance record?	Yes/No	If yes, advise to contact to supplier.
5.6 Spare parts are ready?	Yes/No	If no, advise to prepare.
5.7 Filtering status is OK?	Yes/No	If no, advise to replace.
6 Safety		
6.1 Check operators if he knows well about risk of explosion by biogas	OK/No	Instruct operators about danger of methane.
6.2 Check operators if he knows about danger of H_2S.	OK/No	Instruct operators about danger of H_2S.
6.3 Sign board "Keep fire away" indicated?	Yes/No	If no, ask facility to install.
6.4 Check slurry from toilet biogas does not overflow?	OK/No	If no, countermeasure is necessary.

2.2 Technical Evaluation

Technical evaluation is conducted using data acquisition and analysis of actual energy output, and by making comparisons to the estimated energy output based on feedstock input. Energy efficiency of the biogas system is obtained through technical evaluation.

Necessary data for technical evaluation consists of the following:

- Amount of feedstock input (ton, number of cows, number of humans, etc.)

- Biogas production amount (m^3)
- Generated energy (kWh)
- Amount of slurry (m^3 or number of other possible means of measurement such as buckets)

The above data should be obtained at the site monitoring. For the evaluation, the same conversion method used in planning can be applied. Refer to Chapter 4.2 of Part 1 for details.

(1) Estimation of possible biogas production from feedstock

The biogas production volume per cow can be estimated using the following formula:

$$V_c = 0.033N_c \times W_d \times 365$$

Where, V_c: Volume of biogas production from cow dung (m^3/year)
N_c: Number of cows in facility
W_d: Average cow dung production (kg/cow)

The coefficient 0.033 needs to be adjusted in the range of 0.023-0.04 as described in chapter 4.2 of Part 1. The value of $W_{d,}$ can be applied as 20 kg/cow, for example, but needs to be adjusted as well.

The amount of biogas production from human waste is estimated using the following formula:

$$V_h = 0.024N_h \times O \times D \times R$$

Where, V_h: Volume of biogas production from human waste (m^3/year)
N_h: Number of persons utilizing the toilet connected to a digester in facility
O: Body weight ratio, average weight of persons/average weight of adults
D: Number of regular days (= 365 – number of long holidays))
R: Toilet usage ratio (percentage of toilet use connected to the digester)

The coefficient 0.024 needs to be adjusted in a range 0.02-0.028 as described in chapter 4.2 of Part 1. The value O can be 0.8 if the facility is a high school and 1.0 for an adults' prison. The value D is estimated using school holidays when students and teachers are absent. In general, for schools in Kenya, 0.75 can be applied. The value R is estimated based on an assumption of how often the toilet connected to the digester is used, when different types of toilets not connected to a digester, are installed in a facility. This value should be determined based on interviews and feedback on the situation of the respective school (0.3-1.0).

2.3 Financial and Economic Evaluation

2.3.1 Benefit of biogas

Financial evaluation is conducted with output energy data, which is considered to be the saving from biogas production estimated in technical evaluation. This saving is the benefit of the project converted into financial value.

The method of financial evaluation of the monitoring is the same as that of planning, except that the input and output data should be applied from actual data collected in the site, and comparison against the planned value is necessary.

(1) Benefit of electricity

The benefit of electricity saving is calculated using the following formula.

$$E_g = G_e \times (V_{ce} + V_{he}), \qquad B_e = T \times E_g$$

Where, E_g: Saved amount of electric energy (kWh)
V_{ce} and V_{he} : Volume of biogas V_c and V_h allocated for electricity saving (m^3)
G_e: Efficiency of biogas generator (kWh/m^3)
B_e: Benefit of electricity saving (KSh.)
T: Power tariff rate (KSh./kWh)

The efficiency of biogas generator, G_e depends on specifications of biogas engine generator. For example, 1.0 kWh/m^3 can be applied according to manufacturers' specifications in past projects in the plan. However, in the monitoring, actual efficiency will be obtained from the operation record. Tariff rate T is determined using actual monthly bills of the respective facilities.

(2) Benefit of biogas for cooking stove

The benefit of biogas system consists of fuel wood saving and electricity saving, and can be calculated from the amount of saved fuel wood and/or electricity. The benefit of fuel wood saving is calculated using the following formula:

$$S_f = \frac{(V_{cw}+V_{hw})\times C_{gas}}{C_{wood}/E_{stove}} \ , \qquad B_f = S_f \times P_{wood}$$

Where,
- S_f: Saved amount of fuel wood by biogas (tons/year)
- V_{cw} and V_{hw} : Volume of biogas V_c and V_h allocated for cooking fuel saving (m^3)
- C_{gas}: Calorific value of produced biogas (MJ/m^3)
- C_{wood}: Calorific value of fuel wood (MJ/ton)
- E_{stove}: Efficiency of cooking stove
- B_f: Benefit of fuel wood saving (Ksh)
- P_{wood}: Price of fuel wood (Ksh/ton)

Here, calorific value of produced biogas 20 MJ/m^3 (M. Kaltschmittm, 2003) can be applied for C_{gas}. If gas chromatography analysis is conducted and actual calorific value is determined, the actual value should be applied. The calorific value of fuel wood, C_{wood}, varies depending on the moisture percentage and condition of wood. If users use seasoned wood with a moisture content of 20%, the calorific value is indicated to be 15.5 MJ/kg, according to Table 4.4 of Part 1. This value for example, may be applied in the calculation. E_{stove} value depends on the cooking stove type that the facility uses, and 10% (N.Shrestha, 2001) may be applied in the formula. Fuel wood price, P_{wood}, also varies depending on local conditions. P_{wood} may vary from 3,000-5000 KSh/ton, and this amount should be corrected from user feedback.

An example of economic and financial analysis with assumed cost and production is shown in the chapters below.

2.3.2 Example for Financial Analysis of Biogas Generation System

Financial evaluation is conducted based on actual records collected from the site. An example of gas production and power generation from a biogas project is shown in the table below.

Table 2.3.1 Example of Daily Gas and Energy Production Record

Date	Gas Digester m^3	Generation kWh	⊿Gas m^3	⊿Generation kWh	Efficiency kWh/m^3
:	:	:	:	:	:
23-Oct-12	3,692	4,940	:	:	:
24-Oct-12	3,700	4,957	8.4	16.5	1.96
25-Oct-12	3,710	4,966	9.5	9.8	1.03
26-Oct-12	3,719	4,983	9.2	16.3	1.77
27-Oct-12	3,729	4,999	10	16.3	1.63
28-Oct-12	3,737	5,012	7.8	12.7	1.63
29-Oct-12	3,746	5,022	9.6	10.6	1.10
30-Oct-12	3,755	5,032	9.2	9.9	1.08
31-Oct-12	3,768	5,044	12.9	12.3	0.95
1-Nov-12	3,774	5,057	5.2	12.2	2.35
Average			9.09	12.96	1.43

Average Gas Production per a day from 23/20/12 to 01/11/12	9.09	m^3
Average Generated Energy per a day from 23/20/12 to 01/11/12	12.96	kWh
Total Average Efficiency from 23/20/12 to 01/11/12	1.43	kWh/m^3

Generally, operation records are made according to accumulated gas meter reading and energy meter readings. Thus, daily differences need to be obtained from the actual values. In the above example, the average gas production was 9.09 m^3/day, and the average generated energy was 13.0 kWh/day. This would be the typical production for 24-32 m^3 biogas digester.

The summation of daily differences is tabulated by month and annual biogas production and electric energy generation are calculated. The following table is an example of monthly tabulation of generation results.

Table 2.3.2 Example of Monthly Gas and Energy Production

Month	Gas Digester m^3	Generation kWh	⊿Gas m^3	⊿Generation kWh	Efficiency kWh/m^3
Dec-12	4,328	5,413	:	:	:
Jan-13	4,601	5,781	273	368.1	1.35
Feb-13	4,901	6,186	300	405	1.35
Mar-13	5,181	6,564	280	378	1.35
Apr-13	5,471	6,956	290	391.5	1.35
May-13	5,811	7,415	340	459	1.35
Jun-13	6,131	7,847	320	432	1.35
Jul-13	6,461	8,292	330	445.5	1.35
Aug-13	6,861	8,832	400	540	1.35
Sep-13	7,201	9,291	340	459	1.35
Oct-13	7,551	9,764	350	472.5	1.35
Nov-13	7,884	10,213	333	449.55	1.35
Dec-13	8,249	10,706	365	492.75	1.35
Average			331.64	447.71	1.35

Annual gas production	3,921	m^3
Annual generation amount	5,293	kWh
Average generator efficiency	1.35	kWh/m^3
Electricity tariff rate	25.00	KSh/kWh
Annual benefit of electricity saving	132,323	KSh

From the above table, annual energy generation was 5,293 kWh while gas production was 3,921 m^3. When tariff rate is 25 KSh/kWh (this rate assumes future increases in the tariff, and the current tariff needs to be confirmed and updated by referring to the actual electric bill), the benefit of electricity generation from the biogas system is calculated at KSh. 132,323. This is considered to be the financial benefit of the biogas generation system.

Financial evaluation and FIRR calculation are also conducted for the above example. The conditions are as follows:

- Average Tariff 25.00 KSh/kWh

- Project investment cost 833,299 KSh (example)
- Discount rate 10%
- Project year 30 Years
- Tax 0% (Exempted)
- Annual O&M cost 5% of initial investment
- Other O&M cost 30% of initial investment every 5 years for engine overhaul

The cash flow statement and calculation result of FIRR are shown in the table below.

Table 2.3.3 Sample Financial Evaluation of Biogas Generation System

Financial Analysis (Saving Electricity)

Average Tariff	25.00	KSh/kWh		
Total produced biogas	3,921	m3/year		
Annual energy production	5,293	kWh	1.35	kWh/m3
Annual benefit	132,323	KSh		
Project investment cost	833,299	KSh		
Discount rate	10%			
Project year	30	Years		
Tax	0%	(Exempted)		

No.	Year	Revenue %	Revenue	Cost					Benefit
				Initial Investment	TAX	Rehabilitation	O&M	Total Cost	
			KSh	KSh	KSh	KSh	KSh	KSh	KSh
1	2012	0%	0	833,299	0	0	0	833,299	-833,299
2	2013	100%	132,323		0	0	41,665	41,665	90,658
3	2014	100%	132,323		0	0	41,665	41,665	90,658
4	2015	100%	132,323		0	0	41,665	41,665	90,658
5	2016	100%	132,323		0	0	41,665	41,665	90,658
6	2017	100%	132,323		0	249,990	41,665	291,655	-159,332
7	2018	100%	132,323		0	0	41,665	41,665	90,658
8	2019	100%	132,323		0	0	41,665	41,665	90,658
9	2020	100%	132,323		0	0	41,665	41,665	90,658
10	2021	100%	132,323		0	0	41,665	41,665	90,658
11	2022	100%	132,323		0	249,990	41,665	291,655	-159,332
12	2023	100%	132,323		0	0	41,665	41,665	90,658
13	2024	100%	132,323		0	0	41,665	41,665	90,658
14	2025	100%	132,323		0	0	41,665	41,665	90,658
15	2026	100%	132,323		0	0	41,665	41,665	90,658
16	2027	100%	132,323		0	249,990	41,665	291,655	-159,332
17	2028	100%	132,323		0	0	41,665	41,665	90,658
18	2029	100%	132,323		0	0	41,665	41,665	90,658
19	2030	100%	132,323		0	0	41,665	41,665	90,658
20	2031	100%	132,323		0	0	41,665	41,665	90,658
21	2032	100%	132,323		0	249,990	41,665	291,655	-159,332
22	2033	100%	132,323		0	0	41,665	41,665	90,658
23	2034	100%	132,323		0	0	41,665	41,665	90,658
24	2035	100%	132,323		0	0	41,665	41,665	90,658
25	2036	100%	132,323		0	0	41,665	41,665	90,658
26	2037	100%	132,323		0	249,990	41,665	291,655	-159,332
27	2038	100%	132,323		0	0	41,665	41,665	90,658
28	2039	100%	132,323		0	0	41,665	41,665	90,658
29	2040	100%	132,323		0	0	41,665	41,665	90,658
30	2041	100%	132,323		0	0	41,665	41,665	90,658
		Total	3,837,353	833,299	0	1,249,948	1,208,283	3,291,530	545,822

NPV(Benefit)= 1,127,100 NPV(Cost)= 1,450,333

FIRR=	**3.84%**
RoI=	**16.58%**
NPV=	**-323,233**
B/C=	**0.7771**

In the above example, FIRR is 3.8%. When the project tries to attract private investment, it is necessary for FIRR to be higher than interest rate, net present value (NPV) is a positive value, and B/C (Benefit by Cost) is more than 1.0 at the set discount rate. When discount rate is set at 10% (based on the interest rate of long-term government bonds), NPV value is negative and B/C (Benefit by Cost) is 0.77 as shown in the above table. This means that the project will not attract private investors. However, the total benefit of KSh. 545,822 will be the project benefit and it may still be worthwhile to install the biogas generation system as a public project, if the project is justified in the economic evaluation.

2.3.3 Example of Financial Analysis of Biogas Cooking Fuel Supply

An example of monthly gas production and cooking fuel supply is shown in the table below. Here, it is assumed that all the biogas produced is supplied to the cooking stove. If biogas is supplied to both the cooking stove and generator, it is necessary to calculate financial analysis of the systems independently, according to the amount of gas supplied to each system.

Table 2.3.4 Example of Daily Gas and Energy Production Record

Date	Gas Digester m^3	⊿Gas m^3
Dec-12	4,328	:
Jan-13	4,601	273
Feb-13	4,901	300
Mar-13	5,181	280
Apr-13	5,471	290
May-13	5,811	340
Jun-13	6,131	320
Jul-13	6,461	330
Aug-13	6,861	400
Sep-13	7,201	340
Oct-13	7,551	350
Nov-13	7,884	333
Dec-13	8,249	365
TOTAL		3,921

Annual biogas production	3,921	m^3/year
Gas calorific value	20	MJ/m^3
Calorific value of total produced biogas per year	78,413	MJ/year
Fuelwood calorific value	15.5	MJ/kg
Fuelwood stove efficiency	0.1	
Biogas stove efficiency	0.45	
Converted amount of fuelwood saved by biogas	22.8	ton
Cost of fuelwood	4000	KSh/ton
Annual benefit of fuelwood saving	91,061	KSh

Similarly, it can be assumed that all the gas produced is amount is supplied to the generator for electricity generation.

Financial evaluation and FIRR calculation for the above example can be calculated, as per the following conditions:

- Average fuelwood cost 4,000 KSh/ton
- Annual benefit 91,061 KSh
- Project investment cost 558,310 KSh (assumed)
- Discount rate 10%
- Project year 30 Years
- Tax 0% (Exempted)
- Annual O&M cost 5% of initial investment

The cash flow statement and calculation result of FIRR are as shown in the table below.

Table 2.3.5 Sample of Financial Evaluation of Biogas Cooking Stove

Financial Analysis (Saving Fuelwood)

Average fuelwood cost	4,000	KSh/ton
Total produced biogas	3,921	m3/year
Annual fuelwood saving	22.8	ton
Annual benefit	91,061	KSh
Project investment cost	558,310	KSh
Discount rate	10%	
Project year	30	Years
Tax	0%	(Exempted)

No.	Year	Revenue %	Revenue	Cost					Benefit
				Initial Investment	TAX	Rehabilitation	O&M	Total Cost	
			KSh	KSh	KSh	KSh	KSh	KSh	KSh
1	2012	0%	0	558,310	0	0	0	558,310	-558,310
2	2013	100%	91,061		0	0	27,916	27,916	63,145
3	2014	100%	91,061		0	0	27,916	27,916	63,145
4	2015	100%	91,061		0	0	27,916	27,916	63,145
5	2016	100%	91,061		0	0	27,916	27,916	63,145
6	2017	100%	91,061		0	0	27,916	27,916	63,145
7	2018	100%	91,061		0	0	27,916	27,916	63,145
8	2019	100%	91,061		0	0	27,916	27,916	63,145
9	2020	100%	91,061		0	0	27,916	27,916	63,145
10	2021	100%	91,061		0	0	27,916	27,916	63,145
11	2022	100%	91,061		0	0	27,916	27,916	63,145
12	2023	100%	91,061		0	0	27,916	27,916	63,145
13	2024	100%	91,061		0	0	27,916	27,916	63,145
14	2025	100%	91,061		0	0	27,916	27,916	63,145
15	2026	100%	91,061		0	0	27,916	27,916	63,145
16	2027	100%	91,061		0	0	27,916	27,916	63,145
17	2028	100%	91,061		0	0	27,916	27,916	63,145
18	2029	100%	91,061		0	0	27,916	27,916	63,145
19	2030	100%	91,061		0	0	27,916	27,916	63,145
20	2031	100%	91,061		0	0	27,916	27,916	63,145
21	2032	100%	91,061		0	0	27,916	27,916	63,145
22	2033	100%	91,061		0	0	27,916	27,916	63,145
23	2034	100%	91,061		0	0	27,916	27,916	63,145
24	2035	100%	91,061		0	0	27,916	27,916	63,145
25	2036	100%	91,061		0	0	27,916	27,916	63,145
26	2037	100%	91,061		0	0	27,916	27,916	63,145
27	2038	100%	91,061		0	0	27,916	27,916	63,145
28	2039	100%	91,061		0	0	27,916	27,916	63,145
29	2040	100%	91,061		0	0	27,916	27,916	63,145
30	2041	100%	91,061		0	0	27,916	27,916	63,145
		Total	2,640,759	558,310	0	0	809,550	1,367,860	1,272,899

NPV(Benefit)= 775,639 NPV(Cost)= 745,334

FIRR=	**10.72%**
RoI=	**93.06%**
NPV=	**30,304**
B/C=	**1.0407**

The investment cost for the biogas cooking system is tentatively assumed to be 67% of the investment cost for a biogas generation system. Actual investment cost should be input here. . Since there are no mechanical parts in biogas cooking fuel supply, minimal annual maintenance expenses will be incurred. Accordingly, the financial internal rate of return (FIRR) becomes 10.7%, higher than 10%, which is discount rate. Furthermore, NPV is positive, and B/C is higher than 1.0. This project can therefore be said to be feasible for private investment as well.

Since it is not necessary to include an engine and generator, the costs for initial investment and O&M are lower than that of biogas generation system. This aspect makes FIRR higher for biogas cooking system than biogas generation system for the same digester size.

2.3.4 Example of Economic Analysis for Biogas Generation System

Unlike financial analysis, economic analysis considers both tangible and intangible benefits, not only for the user or investor but also for national social and environmental aspects. According to Chapter 7.4 of Part 1, the economic benefit of biogas generation based on assumed records is calculated as follows.

$$B_{teb} = B_{ed} + B_{cr}$$

Where, B_{eb} : Benefit of electricity saving from diesel oil

B_{cr} :Benefit of carbon reduction by biogas generation

- Price of diesel oil 110 KSh/L
- Efficiency of diesel generation 2.4 kWh/L
- Emission factor of electricity 0.81805 ton-CO_2/MWh
- Price of fuelwood 3,300 KSh/ton
- Exchange rate 86.28 KSh/US$
- Carbon credit 1,294 KSh/ton-CO_2

From the above values, when the generated energy is 5,293 kWh as in the sample, the annual benefits will be as follows:

- Annual economic benefit by diesel oil saving 242,591 KSh
- Annual economic benefit by CO2 reduction 5,603 KSh
- Total economic benefit 248,194 KSh

Based on the above assumptions, the results of economic analysis are shown in the table below.

Table 2.3.6 Sample of Economic Analysis for Biogas Generation

Economic Analysis (Saving Electricity)

Diesel Price	110.00	Ksh/L
Total produced biogas	3,921	m3/year
Annual energy production	5,293	kWh
Annual benefit	248,194	KSh
Project investment cost	952,341	KSh
Discount rate	10%	
Project year	30	Years
Tax	0%	(Exempted)

No.	Year	Revenue %	Revenue	Cost					Benefit
				Initial Investment	TAX	Rehabilitation	O&M	Total Cost	
			KSh	KSh	KSh	KSh	KSh	KSh	KSh
1	2012	0%	0	952,341	0	0	0	952,341	-952,341
2	2013	100%	248,194		0	0	47,617	47,617	200,577
3	2014	100%	248,194		0	0	47,617	47,617	200,577
4	2015	100%	248,194		0	0	47,617	47,617	200,577
5	2016	100%	248,194		0	0	47,617	47,617	200,577
6	2017	100%	248,194		0	285,702	47,617	333,320	-85,125
7	2018	100%	248,194		0	0	47,617	47,617	200,577
8	2019	100%	248,194		0	0	47,617	47,617	200,577
9	2020	100%	248,194		0	0	47,617	47,617	200,577
10	2021	100%	248,194		0	0	47,617	47,617	200,577
11	2022	100%	248,194		0	285,702	47,617	333,320	-85,125
12	2023	100%	248,194		0	0	47,617	47,617	200,577
13	2024	100%	248,194		0	0	47,617	47,617	200,577
14	2025	100%	248,194		0	0	47,617	47,617	200,577
15	2026	100%	248,194		0	0	47,617	47,617	200,577
16	2027	100%	248,194		0	285,702	47,617	333,320	-85,125
17	2028	100%	248,194		0	0	47,617	47,617	200,577
18	2029	100%	248,194		0	0	47,617	47,617	200,577
19	2030	100%	248,194		0	0	47,617	47,617	200,577
20	2031	100%	248,194		0	0	47,617	47,617	200,577
21	2032	100%	248,194		0	285,702	47,617	333,320	-85,125
22	2033	100%	248,194		0	0	47,617	47,617	200,577
23	2034	100%	248,194		0	0	47,617	47,617	200,577
24	2035	100%	248,194		0	0	47,617	47,617	200,577
25	2036	100%	248,194		0	0	47,617	47,617	200,577
26	2037	100%	248,194		0	285,702	47,617	333,320	-85,125
27	2038	100%	248,194		0	0	47,617	47,617	200,577
28	2039	100%	248,194		0	0	47,617	47,617	200,577
29	2040	100%	248,194		0	0	47,617	47,617	200,577
30	2041	100%	248,194		0	0	47,617	47,617	200,577
		Total	7,197,628	952,341	0	1,428,512	1,380,895	3,761,749	3,435,880

NPV(Benefit)= 2,114,073 NPV(Cost)= 1,657,524

EIRR=	**16.60%**
RoI=	**91.34%**
NPV=	**456,550**
B/C=	**1.2754**

In the above table, economic internal rate of return (EIRR) becomes 16.6%, which is higher than social discount rate (SDR) at 10-12%. This means that although FIRR of 3.8% was lower than discount rate and it is difficult for the project to be implemented by business, it is still meaningful to implement as a public project to contribute to national social development.

2.3.5 Example of Economic Analysis for Biogas Cooking Fuel Supply

As explained in Chapter 7.4 of Part 1, the economic benefit of fuelwood reduction is calculated using the following formula.

$$B_{teb} = B_f + B_{fab} + B_{fco} + B_{fev}$$

Where, B_f: Benefit from fuelwood saving

B_{fab}: Fuelwood carbon absorption benefit

B_{fco}: Fuelwood carbon off-set benefit

B_{fev}: Fuel wood economic value to prevent deforestation

When fuelwood saving is 22.8 ton/year as in the sample, the result is calculated as follows:

- Benefit from fuelwood saving 91,061 KSh
- Fuelwood carbon absorption benefit (1) 79.9 ton-CO_2 @3.51 ton-CO_2/ton
- Fuelwood carbon off-set benefit (2) 31.7 ton-CO_2
- Benefit from (1) and (2) 144,451 KSh @1,294 KSh/ton-CO_2
- Fuel wood economic value to prevent deforestation 105,699 KSh
  @4643 KSh/ton
- Total economic benefit for saving fuelwood 341,210 KSh
- Using the above results, economic evaluation is conducted as shown in the table in the next page.
- As shown in the table, the economic internal rate of return (EIRR) is as high as 30.8%. This means that the social validity of conducting biogas projects for fuelwood reduction is high. This is mainly because the estimated economic value of fuelwood is quite high at 4643 KSh/ton, which is higher than fuelwood market price. The economic value applied in this Guideline is calculated from another study[4], and needs to be reviewed by conducting economic analysis of forest reservation in Kenya.
- In this assumption, EIRR of biogas for fuelwood reduction is higher than that of biogas for electricity generation. This also means that economic efficiency of biogas fuelwood reduction is higher than that of biogas generation. To ensure economic feasibility of projects, it would be necessary to ascertain the optimum system, which would be one of the recommendations made for future projects.
- The above results will vary depending on the actual records and assumptions made. It is therefore necessary for the parameters to adjust with collection of actual data and information to increase the accuracy of analysis.

[4] The Role and Contribution of Montane Forests and Related Ecosystem Services to the Kenyan Economy”, 2012, UNEP

Table 2.3.7 Sample of Economic Analysis for Biogas Cooking Fuel Supply

Economicl Analysis (Saving Fuelwood)

Total saved fuelwood	22.77	ton/year
Total produced biogas	3,921	m3/year
Annual energy production	5,293	kWh
Annual economic benefit	341,210	KSh/year
Project investment cost	952,341	KSh/ton
Discount rate	10%	
Project year	30	Years
Tax	0%	(Exempted)

No.	Year	Revenue %	Revenue	Cost					Benefit
				Initial Investment	TAX	Rehabilitation	O&M	Total Cost	
			KSh	KSh	KSh	KSh	KSh	KSh	KSh
1	2012	0%	0	952,341	0	0	0	952,341	-952,341
2	2013	100%	341,210		0	0	47,617	47,617	293,593
3	2014	100%	341,210		0	0	47,617	47,617	293,593
4	2015	100%	341,210		0	0	47,617	47,617	293,593
5	2016	100%	341,210		0	0	47,617	47,617	293,593
6	2017	100%	341,210		0	0	47,617	47,617	293,593
7	2018	100%	341,210		0	0	47,617	47,617	293,593
8	2019	100%	341,210		0	0	47,617	47,617	293,593
9	2020	100%	341,210		0	0	47,617	47,617	293,593
10	2021	100%	341,210		0	0	47,617	47,617	293,593
11	2022	100%	341,210		0	0	47,617	47,617	293,593
12	2023	100%	341,210		0	0	47,617	47,617	293,593
13	2024	100%	341,210		0	0	47,617	47,617	293,593
14	2025	100%	341,210		0	0	47,617	47,617	293,593
15	2026	100%	341,210		0	0	47,617	47,617	293,593
16	2027	100%	341,210		0	0	47,617	47,617	293,593
17	2028	100%	341,210		0	0	47,617	47,617	293,593
18	2029	100%	341,210		0	0	47,617	47,617	293,593
19	2030	100%	341,210		0	0	47,617	47,617	293,593
20	2031	100%	341,210		0	0	47,617	47,617	293,593
21	2032	100%	341,210		0	0	47,617	47,617	293,593
22	2033	100%	341,210		0	0	47,617	47,617	293,593
23	2034	100%	341,210		0	0	47,617	47,617	293,593
24	2035	100%	341,210		0	0	47,617	47,617	293,593
25	2036	100%	341,210		0	0	47,617	47,617	293,593
26	2037	100%	341,210		0	0	47,617	47,617	293,593
27	2038	100%	341,210		0	0	47,617	47,617	293,593
28	2039	100%	341,210		0	0	47,617	47,617	293,593
29	2040	100%	341,210		0	0	47,617	47,617	293,593
30	2041	100%	341,210		0	0	47,617	47,617	293,593
		Total	9,895,098	952,341	0	0	1,380,895	2,333,237	7,561,861
		NPV(Benefit)=	2,906,369				NPV(Cost)=	1,271,359	

EIRR=	**30.82%**
RoI=	**324.09%**
NPV=	**1,635,010**
B/C=	**2.2860**

2.4 Utilization of Effluent

A digester connected to a cow shed, and using cow dung as feedstock generates effluent as a byproduct which can be utilized for gardening of vegetables such as beans and kale (*Sukuma*) and animal feed.

Following photos are example of *Sukuma* with manure, showing good growth and high yield.

Figure 2.3.1 Sukuma Gardens with Biogas Slurry

If the elevation of the garden is higher than the digester, gardening with manure requires transportation work. However, if the garden is located below the elevation of the digester, manure can be supplied automatically by gravity and gardening only requires constructing a ditch from the effluent chamber. Such consideration is recommended and should be incorporated in the initial planning for other sites.

For evaluation purposes, if possible, the user can be requested to test growth and yield of the garden with (i) no fertilizer, (ii) biogas slurry, and (iii) chemical fertilizer, in order to obtain data to determine the benefit of biogas slurry.

With actual data on the difference in yield between (ii) and (i), and price of chemical fertilizer, the economic benefit of biogas slurry can be estimated.

A sample form for recording production yield from gardening with biogas slurry is shown in the table below.

Table 2.3.8 Form of Recording of Production Yield with Biogas Slurry

Form for Recording Production Yield with various Fertilizer

Year/Month: ____________ Location: ____________

Operator Name: ____________ Approved by: ____________

Product Type: ____________

Date	Method	Unit	Inorganic fertilizer	Raw cow dung	Biofertilizer	No fertilizer
	Bucket, Wheelbarrow, Weigh, Other (Specify)	Times, kg, etc.				

According to the above test, financial and economic value of slurry can be calculated. The following table is an example of calculated value of biogas slurry determined by simple comparison of vegetable yield without any fertilizer against yield with biogas slurry addition.

Table 2.3.9 Example of Benefit Calculation of Biogas Slurry

(1)	Market price of vegetable	100 KSh/kg
(2)	Vegetable yield with no fertilizer	0.2 kg/m^2
(3)	Vegetable yield with chemical fertilizer	0.3 kg/m^2
(4)	Vegetable yield with biogas slurry	0.4 kg/m^2
(5)	Amount of biogas slurry application per area per day	0.25 kg/m$^{2/}$day
(6)	Production of biogas slurry per year	200 kg/day
(7)	Benefit of slurry per one gardening [= (6) / (5) x ((4)- (2)) x (1)]	16,000 KSh/times
(8)	Gardening cultivation times per year	4 times/year
(9)	Annual benefit of slurry [= (7) x (8)]	64,000 KSh/year

In the above example, if biogas slurry application at 0.25 kg/m^2/day increases the yield of vegetables by 0.2 kg/m^2 and the value of the vegetable is 100 KSh/kg; the annual benefit will be 64,000 KSh/year. This value can be added to both economic and financial benefit in economic and financial evaluation.

If data on application of chemical fertilizer is available, it should also be compared with the actual yield and value, and price of chemical fertilizer. In this case, a higher benefit value may be applied for both economic and financial evaluation.

CHAPTER 3 ENVIRONMENTAL MANAGEMENT

In order to maintain environmental sanitation around the biogas facility (digester) as well as to ensure safety of biogas, the following countermeasures are necessary to be monitored and ensured to be taken.

(1) De-Sludge Management

- ✓ The slurry from toilet-connected biogas should be properly managed without leakage to the environment.
- ✓ If there is leakage from existing pit or septic tank, twin leaching pits method can be applied for biogas projects to manage wastewater and de-sludge activities simultaneously.

(2) Effluent Management

- ✓ Soak- way method can be applied for the effluent discharge from the facility to the surrounding environment to avoid contamination of ground water.

(3) Methane Gas Knowledge

- ✓ Basic knowledge of Methane Gas properties shall be confirmed to be imparted to stakeholders to ensure that they understand safety of the biogas project.
- ✓ Physical conditions for explosions and countermeasures are as follows:
  1. 5.3% to 14% of Methane gas concentration in the atmosphere can explode.
     - ➢ Daily checks for gas leakage by checking to hear sounds of leakage and by checking for abnormal consumption rate.
  2. Ignition point is necessary.
     - ➢ Do not use any fire at the site, including smoking cigarettes and eliminate static electricity.
- ✓ Basic knowledge sharing of hydrogen sulfide (H_2S) about toxicity shall also be confirmed.

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ANNEXES

Annex-1	Form for Survey, Monitoring and evaluation
Annex-2	Drawings

Annex-1 Forms

Confirmation Items for Biogas Generation Planning

Confirmed by: **Location:** **Date:**

Confirmation Item	Unit	Description	Remarks
Basic Information			
Date of site survey			
Name of the facility			
Location (County, sublocation, location, village)			
Coordinate (Latitude, longitude, elevation)			
Distance from Nairobi			
Grid connected?, Nearest grid connection in km			
Financed by			
Establishment year			
Major ethnic group			
Name of manager (principal, teacher, head, etc)			
Organization structure			
Availability of technician and operator			
Type of geology, geological structure			
Salary level of staffs			
Operation hours			
Contact address and number			
Possible feedstock input			
Nos of cows	nos		
Nos of pigs or nos of pultry	nos		
Nos of students (total)	nos		
Nos of students (boarding, period of boarding)	nos		
Nos of teacher and staff	nos		
Nos of teacher (living)	nos		
Type of toilet and percentage of use for each type			
Water usage for toilet cleaning	L/day, t/day		
Raw waste material (food, vegetable waste, etc)			
Garden or caltivation near the site			
Current energy usage	Unit	Amount, remarks	
Electricity usage	kWh/mon		
Electricity tariff payment record (from bills, average in several months)	Ksh/mon		
Current use of electric/heat appliance (type, hours) Light, PC, mobile charge, TV, radio, cooking heater, other			
Diesel generator and oil for generation, if any, cost	L/day, L/mon, Ksh/L		
Type of fuel for cooking (Fuel wood, LPG, etc)			
Current usage of fuel wood, cost	kg/day, t/mon, Ksh/ton		
Current usage of LPG, cost	cylinder(kg)/mon Ksh/Cylinder		
Current usage of other fuel	unit, amount, Ksh/unit		
Source of water supply (pump, etc.)			
Type of lighting			
Priority usage of gas (electricity, fuel, etc)			
Other Remarks			

Monitoring Form of Biogas Generation System: Base Information Sheet

Date/Month/Year: ____________ Location: ____________

Operator Name ____________ Approved by: ____________

Monitoring conducted by: ____________

1. Data for Cow Dung Digester:

   Nos of cow (for digester) Mature: ________ Child: ________ Total: ________

   Average amount of dung per cow (20 kg/cow, as standard) ________ kg/cow

2. Data for Digester connected with Toilet:

   Nos of users of toilet connected with digester ________ Ratio of daily use of toilet connected with digester ________

   Average weight of ratio of users of toilet (user average/adult average) ________

3. Fuel Wood Usage (compare current and before system installation, if possible)

   3.1 Current use of fire wood ________ times/year by truck, wheel-barrow, other
   Truck ________ times/year ________ kSh/time
   Wheel barrow ________ times/year ________ kSh/time
   Other ( ) ________ times/year ________ kSh/time
   3.2 Total use of fuel wood : ________ ton/year (times/year x kg/times as indicated above)

   If possible, obtain following data of the period before biogas system installation for reference:

   3.3 Use of fire wood before system ________ times/year by truck,wheel-barrow, other
   Truck ________ kg/times
   Wheel barrow ________ kg/times
   Other ( ) ________ kg/times
   3.4 Total use of fuel wood : ________ ton/year (times/year x kg/times as indicated above)
   3.5 Difference before and after installation of biogas system (3.4 - 3.2) ________ ton/year
   (This is just a reference value. Actual difference fuel wood saving should be calculated by produced amount of biogas)

4. Electric Energy Usage (obtain electricity bill of Kenya Power from the user)

   4.1 Current electricity payment of the month ________ kSh/month
   4.2 Current electricity usage ________ kWh/month

   If possible, obtain following data of the period before biogas system installation for reference.
   The bill should be the same month of the monitoring.

   4.3 Electricity payment of the same month ________ kSh/month
   4.4 Electricity usage of the same month ________ kWh/month
   4.5 Difference of tariff before and after installation of biogas system (4.3 - 4.1) ________ kSh/month
   4.6 Difference of electric energy before and after installation of biogas system (4.3 - 4.1) ________ kWh/month
   (4.5 and 4.5 are just a reference value. Actual electricity saving should be calculated by the electric meter)

5. Total gas production per month ________ m^3/month
   Gas used for cooking fuel per month ________ m^3/month
   Gas used for energy generation per month ________ m^3/month
6. Total electric energy production per month ________ kWh/month
   (Gas and Electric Energy Data Sheet should be used for 5. and 6. above.)

7. Cost of firewood ________ kSh/ton (calculate from 3.1 and 3.2)
8. Tariff rate ________ kSh/kWh

O&M Form of Biogas Generation System: Gas and Electric Energy Data Sheet

Year/Month: ____________________ Location: ____________________

Operator Name ____________________ Approved by: ____________________

Date	Day	Time	Gas Production					Generation Data		
			Digester-1	Digester-2	Digester-3	Gas Bag	Daily	Max Power	Energy	Daily
			m^3	m^3	m^3	m^3	m^3	kW	kWh	kWh
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
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29										
30										
31										

* The sheet needs to be recorded every day, submitted to manager monthly, and submitted to REA bi-annually.

** "Daily" means production of the day, difference of the amount yesterday and today.

Maintenance Record

Date/Month/Year: ______________________ Location: ______________________

Operator Name ______________________ Approved by: ______________________

Maintenance Item: Engine / Generator / Filter / Gas Bag / Pipe / Valve / Digester / Other ( )

Problem : ______________________

Maintenance work component: ______________________

Cause of problem and prevention method: ______________________

Approximate Cost: ______________________ Ksh

Maintenance Record

Date/Month/Year: ______________________ Location: ______________________

Operator Name ______________________ Approved by: ______________________

Maintenance Item: Engine / Generator / Filter / Gas Bag / Pipe / Valve / Digester / Other ( )

Problem : ______________________

Maintenance work component: ______________________

Cause of problem and prevention method: ______________________

Approximate Cost: ______________________ Ksh

Form for Recording Production Yield with various Fertilizer

Year/Month: ____________________ Location: ____________________

Operator Name: ____________________ Approved by: ____________________

Product Type: ____________________

Date	Method	Unit	Inorganic fertilizer	Raw cow dung	Biofertilizer	No fertilizer
	Bucket, Wheelbarrow, Weigh, Other (Specify)	Times, kg, etc.				

Format of Site Survey in Monitoring

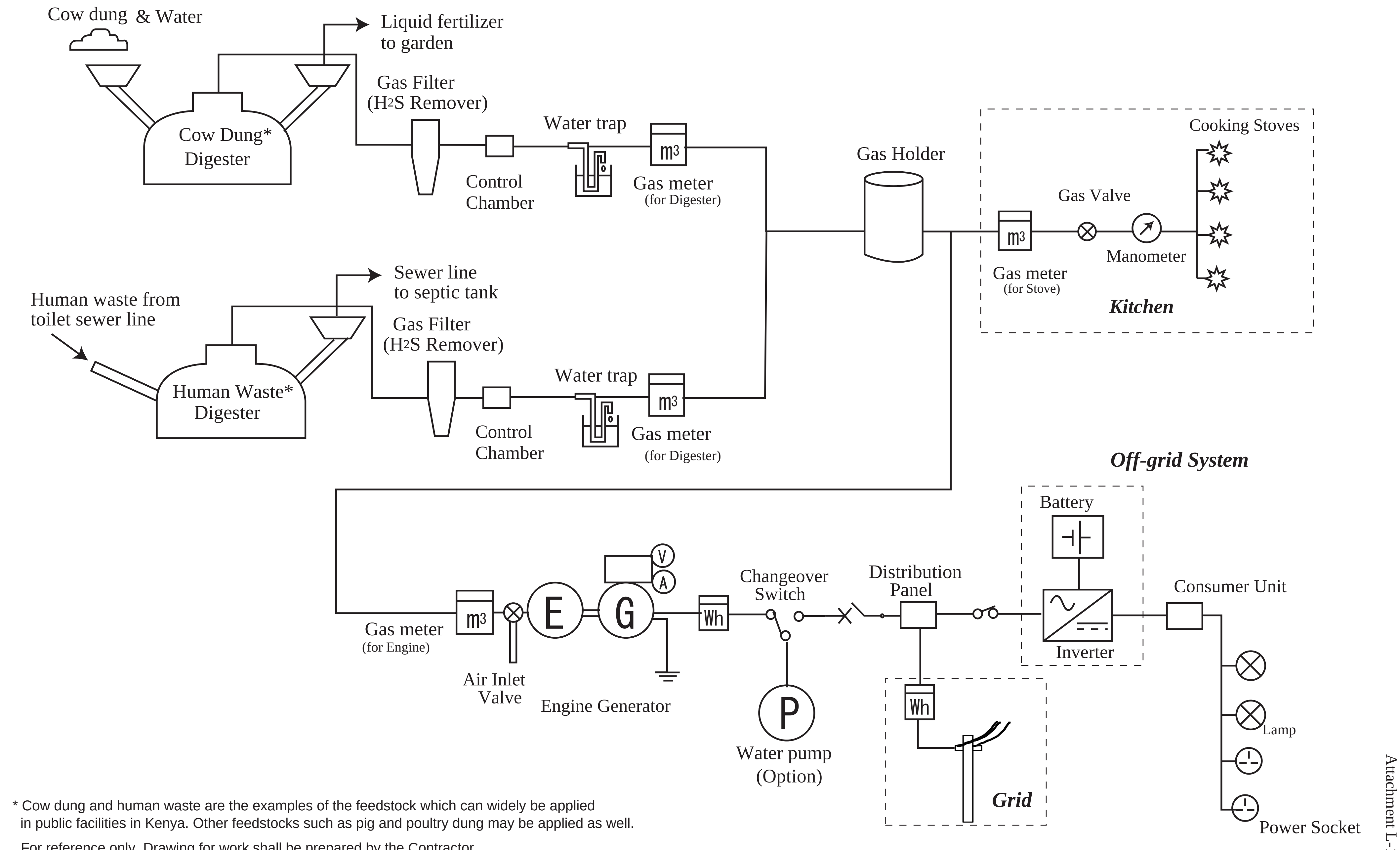
Date: _______________ Inspected by: ____________________ Operator/Facility owner:________________

Items	Select	Remarks
1 Biogas digester		
1.1 Are there no leakage from valve?	Yes/No	If yes, valve replacement necessary.
1.2 Does it smell with odor?	Yes/No	If yes, check if there is no leakage.
1.3 Are there no crack on concrete and brick?	Yes/No	If yes, repair is necessary.
1.4 Does the flow meter work well without rust?	Yes/No	If no, meter replacement necessary.
1.5 Check flow rate.	______	m^3
2 Toilet and septic tank (connected with digester)		
2.1 Are there no overflow?	Yes/No	If yes, inform facility to deal with it.
2.2 Are there no odor?	Yes/No	If yes, inform facility to deal with leakage.
2.3 Chlorine detergent and antibiotics are used in toilet?	Yes/No	If yes, instruct facility to prohibit, and tell them it will damage bacteria in digester.
2.4 Extra waste (sanitary waste, paper, etc) flows to digester?	Yes/No	If yes, instruct facility to educate user not to do.
3 Pipeline and manhole		
3.1 Are there no leakage?	Yes/No	If yes, repair is necessary.
3.2 Conduct visual inspection if there is no failure.		
3.3 Conduct sampling of biogas, if necessary. (Note: Keep fire away!)	(for gas analysis)	
4 Gas bag		
4.1 Are there no leakage?	Yes/No	If yes, repair is necessary.
4.2 Does it smell with odor?	Yes/No	If yes, leaked. Check through.
4.3 Are fitting and pipes fine without loose connection?	Yes/No	If no, replace the part.
4.4 Check the accumulated flow.	______	m^3
5 Power house and engine-generator		
5.1 Engine starting and operation no problem?	Yes/No	If no, advise to contact to supplier.
5.2 Check output.	_____	kW, A, V
5.3 Check accumulated energy	______	kWh
5.4 Engine operates without strange noise?	Yes/No	If no, advise to contact to supplier.
5.5 Same failure repeated in maintenance record?	Yes/No	If yes, advise to contact to supplier.
5.6 Spare parts are ready?	Yes/No	If no, advise to prepare.
5.7 Filtering status is OK?	Yes/No	If no, advise to replace.
6 Safety		
6.1 Check operators if he knows well about risk of explosion by biogas	OK/No	Instruct operators about danger of methane.
6.2 Check operators if he knows about danger of H_2S.	OK/No	Instruct operators about danger of H_2S.
6.3 Sign board "Keep fire away" indicated?	Yes/No	If no, ask facility to install.
6.4 Check slurry from toilet biogas does not overflow?	OK/No	If no, countermeasure is necessary.

Notes, instruction, and advise from the inspection:

Annex-2 Drawings

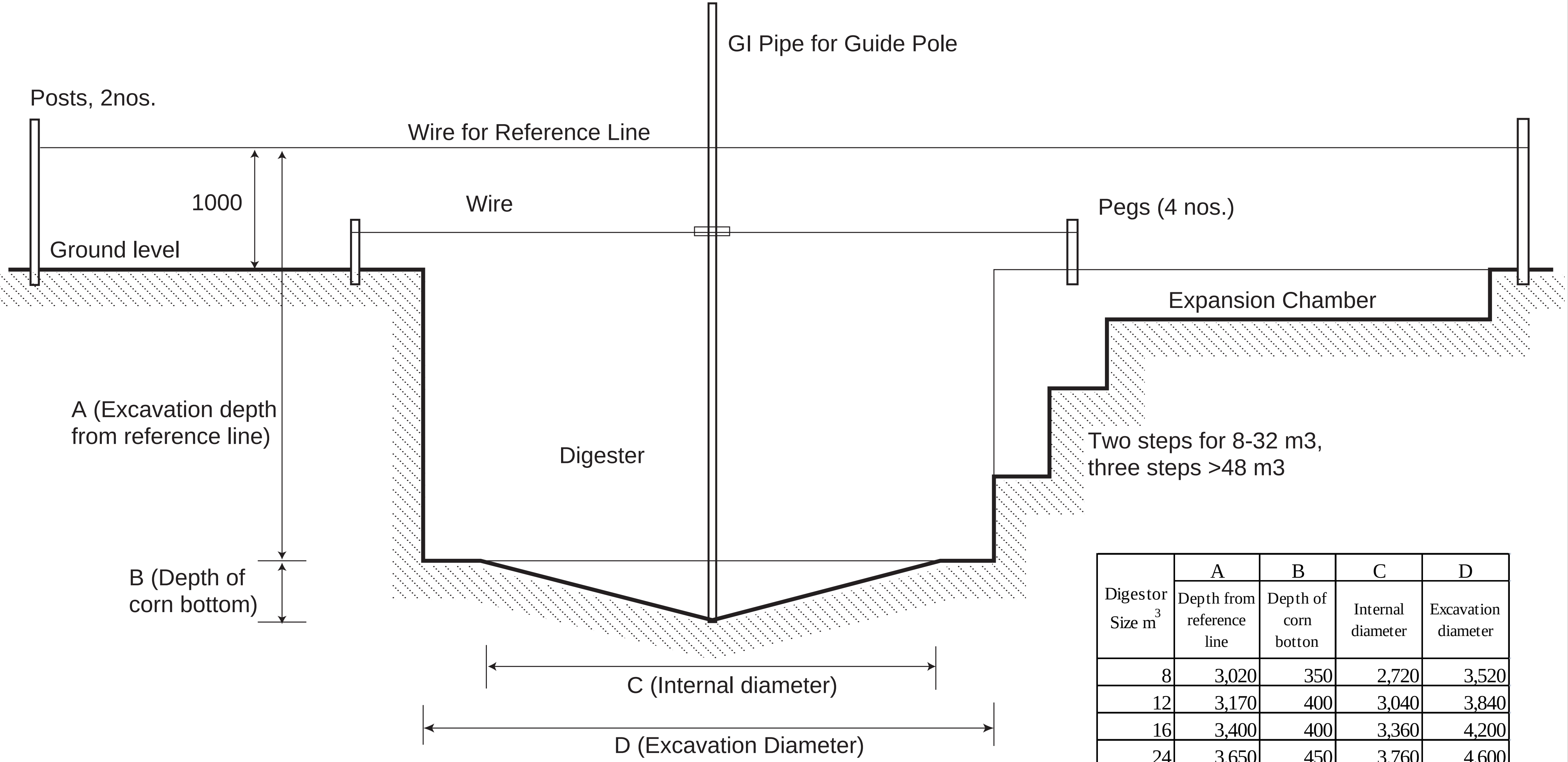
Drawing No. G-01	Conceptual Diagram of Biogas System Flow
Drawing No. G-02	AKUT Type Biogas Digester (8-124 m^3) Excavation Plan
Drawing No. G-03-1	AKUT Type Biogas Digester (8-32 m^3)
Drawing No. G-03-2	AKUT Type Biogas Digester (48-124 m^3)
Drawing No. G-04	Control Chamber and Water Trap
Drawing No. G-05	Reinforcement Plan and Digester Manhole



* Cow dung and human waste are the examples of the feedstock which can widely be applied in public facilities in Kenya. Other feedstocks such as pig and poultry dung may be applied as well.

For reference only. Drawing for work shall be prepared by the Contractor.

Conceptual Diagram of Biogas System Flow (Example of Power Supply to Water Pump and Lighting)	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No.: G-01



Digestor Size m^3	A Depth from reference line	B Depth of corn botton	C Internal diameter	D Excavation diameter
8	3,020	350	2,720	3,520
12	3,170	400	3,040	3,840
16	3,400	400	3,360	4,200
24	3,650	450	3,760	4,600
32	3,900	550	4,160	5,000
48	4,300	600	4,800	5,600
59	4,500	600	5,120	5,920
71	4,700	650	5,440	6,240
91	4,900	750	5,920	6,700
124	5,250	800	6,560	7,300

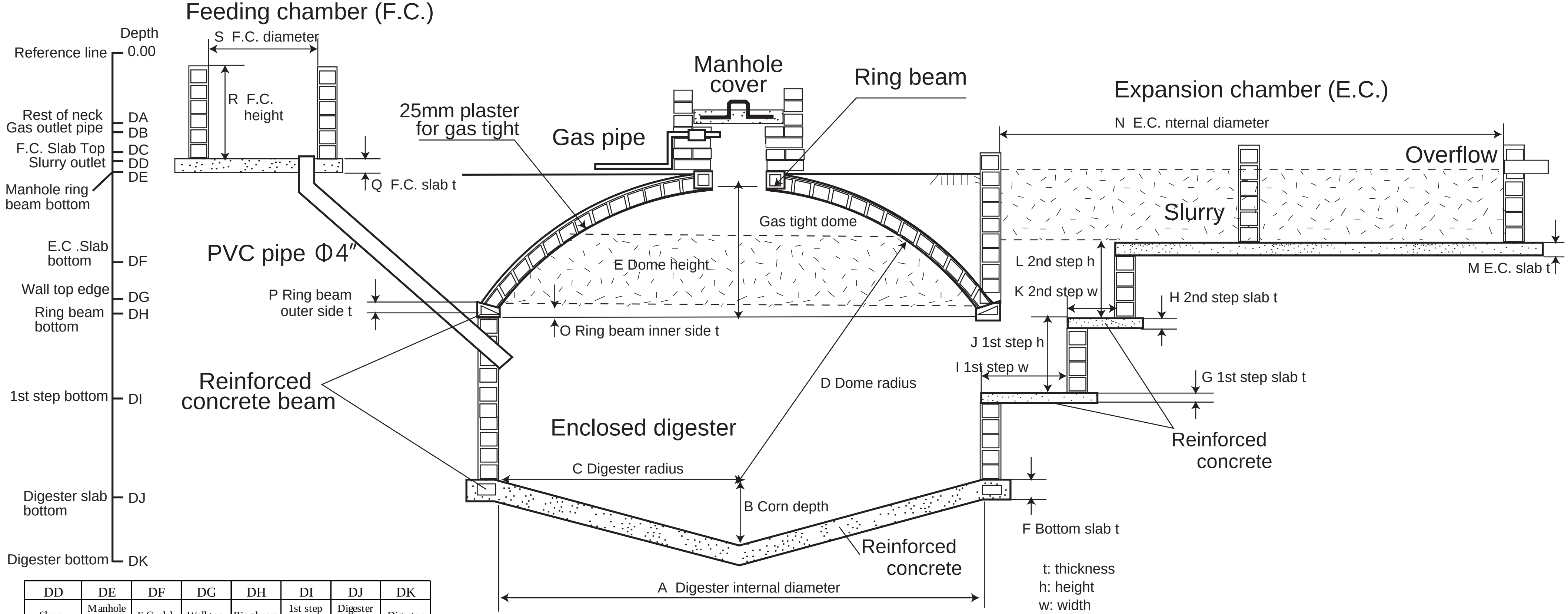
For reference only. Drawing for work shall be prepared by the Contractor.

Attachment L-1

AKUT Fixed Dome Type Biogas Digester (8-124 m3) Excavation Plan	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No.: G-02

Dimension of Fixed Dome Digester (mm)

Digester Size m^3	A Digester internal diameter	B Corn depth	C Digester radius	D Dome radius	E Doem height	F Bottom slab thickness	G 1st step slab thickness	H 2nd step slab thickness	I 1st step slab width	J 1st step slab height	K 2nd step slab width	L 2nd step slab height	M E.C. slab thickness	N E.C. internal diameter	O Ring beam inner side thichness	P Ring beam outer side thichness	Q F.C. slab thickness	R F.C. height	S F.C. diameter
8	2,720	350	R1360	R1700	770	120	100	100	750	550	400	550	100	2,280	60	170	100	800	1,000
12	3,040	400	R1520	R1900	820	120	100	100	750	600	400	500	100	2,720	60	170	100	800	1,000
16	3,360	400	R1680	R2100	900	150	100	100	750	600	400	600	100	3,200	60	170	100	800	1,000
24	3,760	450	R1880	R2350	1,000	150	100	100	750	650	400	650	100	3,800	60	170	100	800	1,000
32	4,160	550	R2080	R2600	1,100	150	100	100	750	650	400	650	100	4,360	60	170	100	800	1,000



DD Slurry outlet	DE Manhole ring beam bottom	DF E.C. slab bottom	DG Wall top edge	DH Ring beam bottom	DI 1st step slab bottom	DJ Digester slab bottom	DK Digester bottom
1,000	1,200	1,600	1,880	1,940	2,700	3,020	3,370
1,000	1,150	1,600	1,910	1,970	2,070	3,170	3,600
1,000	1,150	1,600	1,990	2,050	2,800	3,400	3,800
1,000	1,150	1,600	2,090	2,150	2,900	3,650	4,100
1,000	1,150	1,600	2,190	2,250	2,900	3,900	4,550

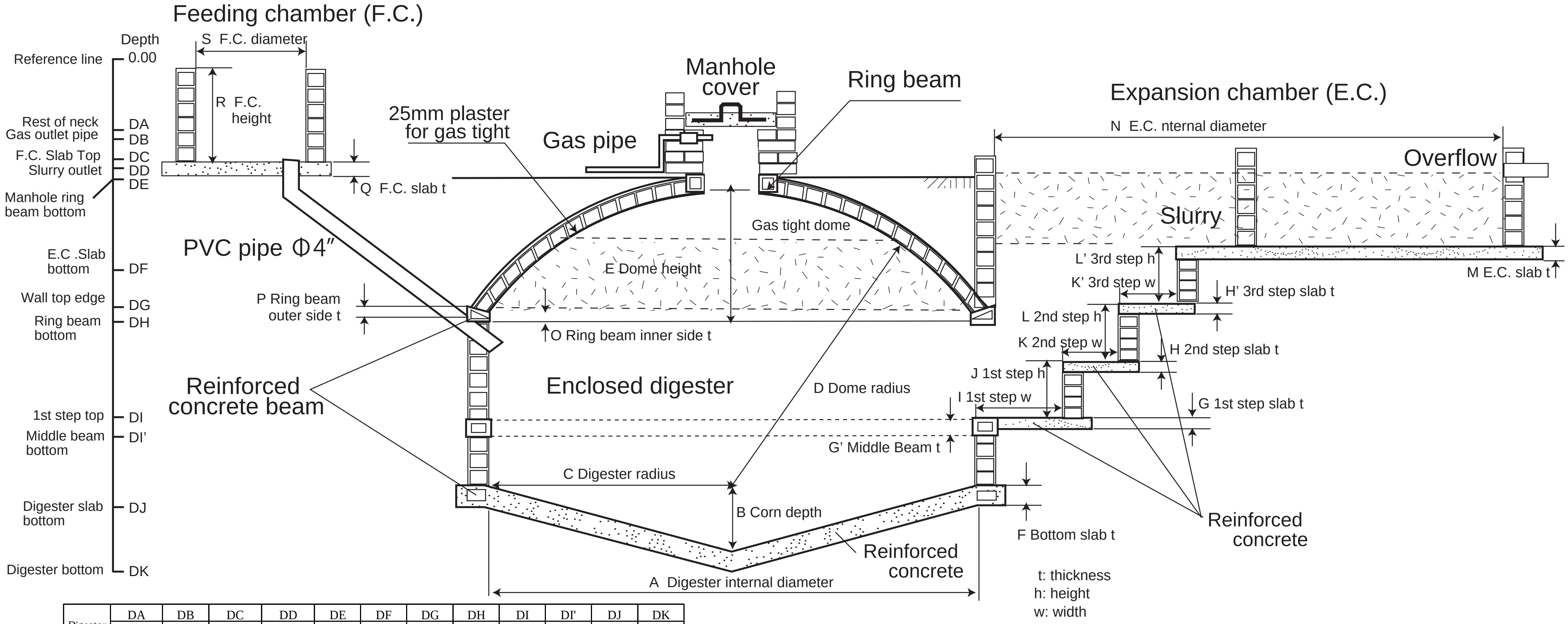
Attachment L-1

For reference only. Drawing for work shall be prepared by the Contractor.

AKUT Fixed Dome Type Biogas Digester (8-32 m^3)	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No.: G03-1

Dimension of Fixed Dome Digester (mm)

Digestor Size m^3	A Digester internal diameter	B Corn depth	C Digester radius	D Dome radius	E Dome height	F Bottom slab thickness	G 1st step slab thickness	G' Middle beam thickness	H 2nd step slab thickness	H' 3rd step slab thickness	I 1st step slab width	J 1st step slab height	K 2nd step slab width	K' 3rd step slab width	L 2nd step slab height	L' 3rd step slab height	M E.C. slab thickness	N E.C. internal diameter	O Ring beam inner side thichness	P Ring beam outer side thichness	Q F.C. slab thickness	R F.C. height	S F.C. diameter
48	4,800	600	R2400	R3000	1,050	150	120	150	120	100	750	610	400	400	610	620	100	4,600	90	200	100	800	1,100
60	5,120	600	R2560	R3200	1,280	150	120	130	120	100	750	620	400	400	620	620	100	5,260	90	200	100	800	1,100
71	5,440	650	R2720	R3400	1,360	150	100	160	100	100	700	670	400	400	670	670	100	5,560	120	230	100	800	1,200
91	5,920	750	R2960	R3700	1,480	150	100	150	100	100	700	730	400	400	750	750	100	6,260	120	230	100	800	1,200
124	6,560	800	R3280	R4100	1,640	150	100	180	100	100	600	850	400	400	850	850	100	7,040	120	230	100	800	1,200



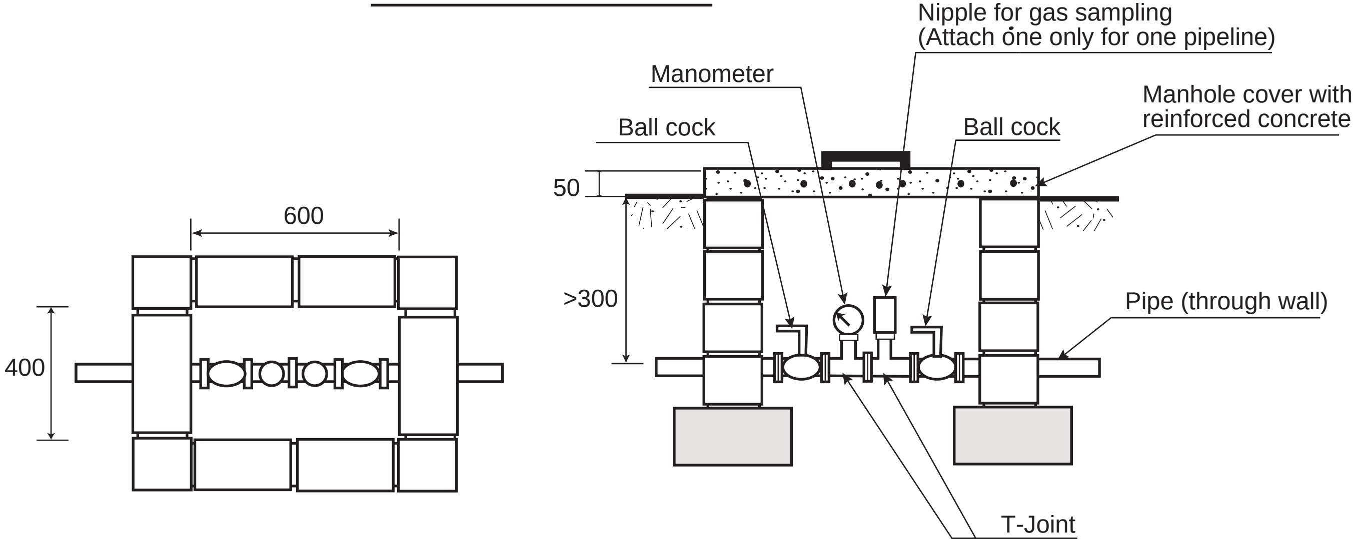
Digestor Size m^3	DA Rest of neck	DB Gas outlet pipe	DC F.C. slab top	DD Slurry outlet	DE Manhole ring beam bottom	DF E.C. slab bottom	DG Wall top edge	DH Ring beam bottom	DI 1st step slab top	DI' Middle beam bottom	DJ Digester slab bottom	DK Digester bottom
48	550	650	900	1,000	1,150	1,600	2,350	2,440	3,340	3,490	4,300	4,900
59	550	650	900	1,000	1,150	1,600	2,430	2,520	3,360	3,490	4,500	5,250
71	550	650	900	1,000	1,150	1,600	2,510	2,630	3,510	3,670	4,700	5,350
91	550	650	900	1,000	1,150	1,600	2,530	2,650	3,730	3,880	4,900	5,650
124	550	650	900	1,000	1,150	1,600	2,640	2,760	4,060	4,240	5,250	6,050

For reference only. Drawing for work shall be prepared by the Contractor.

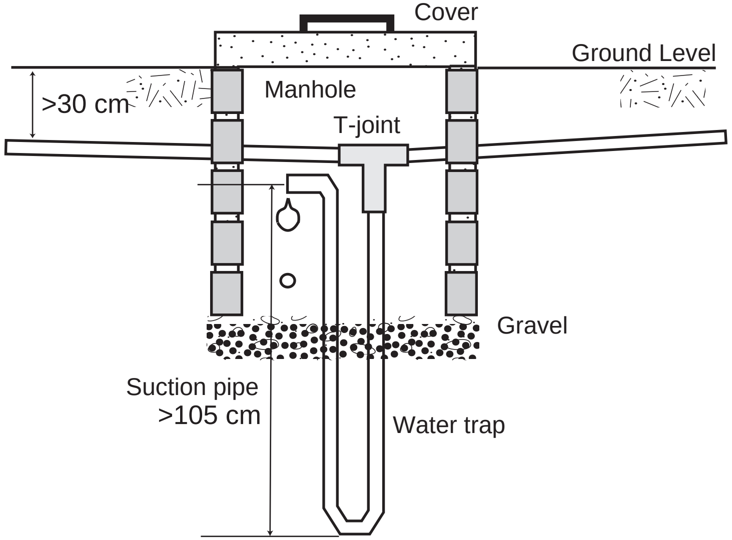
Attachment L-1

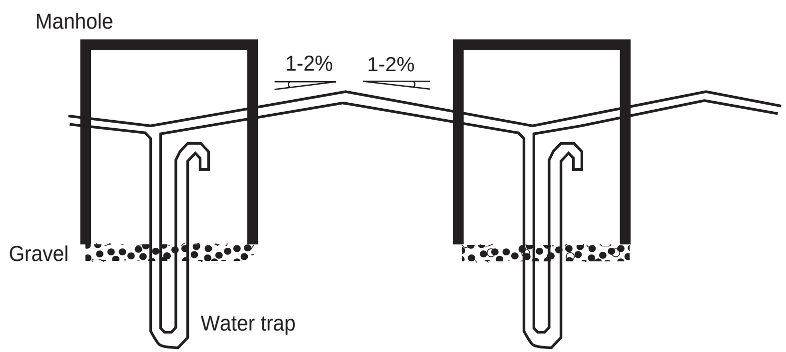
AKUT Fixed Dome Type Biogas Digester (48-124 m3)	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No.: G03-2

Control Chamber



Water Trap Chamber of Gas Pipeline





Conceptual figure of slope of water trap and gas pipe

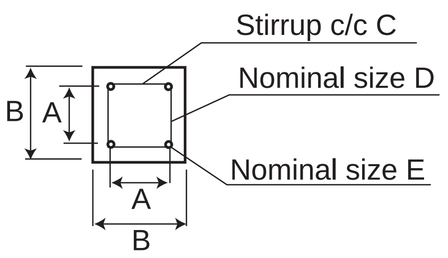
Attachment L-11

For reference only. Drawing for work shall be prepared by the Contractor.

Fixed Dome Type Biogas Digester (8-124 m^3) Control Chamber and Water Trap	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No: G-04

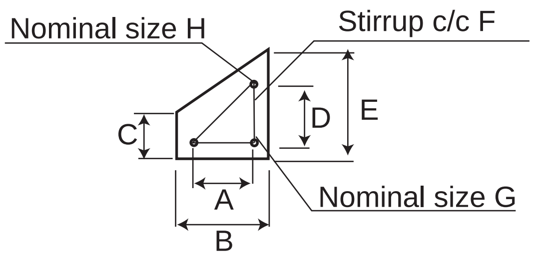
Beam Reinforcements

Manhole



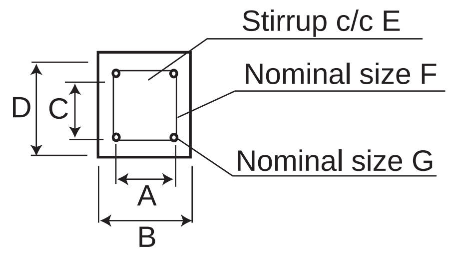
Digestor Size m^3	A Steel bar width/ height	B Beam width/ height	C Stirrup C/C mm	D Bar nominal size	E Bar nominal size
8	100	150	c/c 200	R6	R8
12	100	150	c/c 200	R6	R8
16	100	150	c/c 200	R6	R8
24	100	150	c/c 200	R6	R8
32	100	150	c/c 200	R6	R8
48	100	150	c/c 200	R6	R8
60	100	150	c/c 200	R6	R8
71	100	150	c/c 200	R6	R8
91	100	150	c/c 200	R6	R8
124	100	150	c/c 200	R6	R8

Ring beam



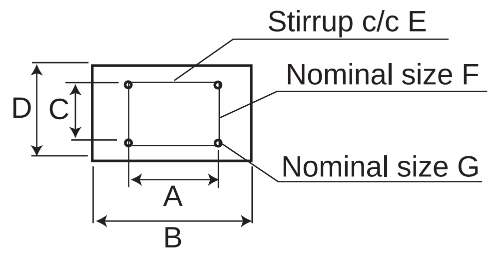
Digestor Size m^3	A Steel bar width	B Beam width	C Beam height small	D Steel bar height	E Beam height large	F Stirrup C/C mm	G Bar nominal size	H Bar nominal size
8	100	150	60	100	170	c/c 300	R6	R8
12	100	150	60	100	170	c/c 300	R6	R8
16	100	150	60	100	170	c/c 300	R6	R8
24	100	150	60	100	170	c/c 300	R6	R8
32	100	150	60	100	170	c/c 300	R6	R8
48	100	150	90	100	200	c/c 300	R6	R8
60	100	150	90	100	200	c/c 300	R6	R8
71	100	150	120	100	230	c/c 300	R6	R8
91	100	150	120		230	c/c 300	R6	R8
124	100	150	120	100	230	c/c 300	R6	R8

Middle beam



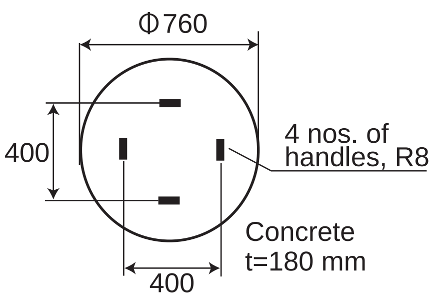
Digestor Size m^3	A Steel bar width	B Beam width	C Steel bar height	D Beam height	E Stirrup C/C mm	F Bar nominal size	G Bar nominal size
8	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-
48	100	150	100	150	c/c 300	R6	R8
60	100	150	100	130	c/c 300	R6	R8
71	100	150	100	160	c/c 300	R6	R8
91	100	150	100	150	c/c 300	R6	R8
124	100	150	120	180	c/c 300	R6	R8

Base beam

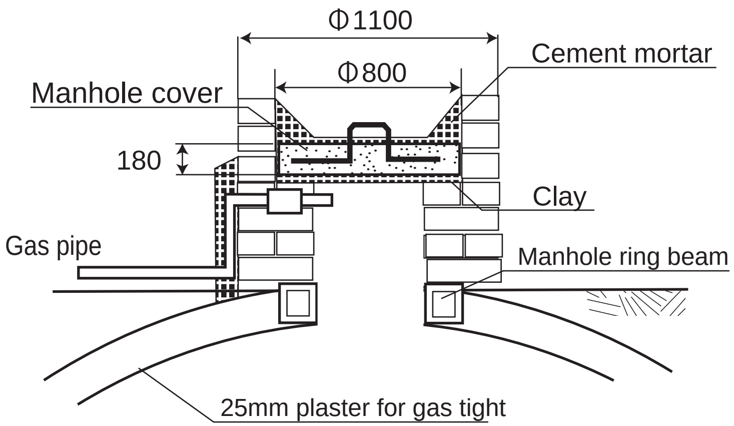


Digestor Size m^3	A Steel bar width	B Beam width	C Steel bar height	D Beam height	E Stirrup C/C mm	F Bar nominal size	G Bar nominal size
8	100	200	80	120	c/c 300	R6	R8
12	100	200	80	120	c/c 300	R6	R8
16	100	250	100	150	c/c 300	R6	R8
24	100	250	100	150	c/c 300	R6	R8
32	100	250	100	150	c/c 300	R6	R8
48	100	250	100	150	c/c 300	R6	R8
60	100	250	100	150	c/c 300	R6	R8
71	150	250	100	150	c/c 300	R6	R8
91	150	250	100	150	c/c 300	R6	R8
124	150	250	100	150	c/c 300	R6	R8

Manhole Cover



Digester Manhole



Attachment L-1

For reference only. Drawing for work shall be prepared by the Contractor.

AKUT Fixed Dome Type Biogas Digester (8-124 m3) Reinforcement Plan and Digester Manhole	Rural Electrification Authority	Scale: NTS	Drawn by:
		Version: 0.1	Checked by:
		Date: 12/11/14	Drawing No.: G-05

PROJECT FOR ESTABLISHMENT OF RURAL ELECTRIFICATION MODEL USING RENEWABLE ENERGY

GUIDELINE FOR BIOGAS GENERATION

NOV 2014

Objectives

- Objective of Guideline:
  - To establish a guideline manual that will be used as a reference material.
- Objective of Validation Workshop:
  - To obtain feedback and comments from stakeholders in biogas energy development.
  - Compile a biogas guideline manual for generation of biogas

Overall Contents

Part-1 Guideline for Biogas Generation System Planning

- For planner, project implementing and executing agency

Part-2 User Guideline for Biogas Generation Operation

- For user (schools and facilities)

Part-3 Guideline for Monitoring and Evaluation

- For project financer, implementing and executing agency

INTRODUCTION

- Biomass is the organic material which is utilized as energy, material source is mainly agricultural, industrial and human waste.
- Biogas is the fuel gas that is produced by the anaerobic fermentation of organic material by methane producing bacteria, this process is determined by several conditions.
- Design of the various digester sizes has always been left at the discretion of a particular contractor who has been awarded the assignment especially for the school projects which have been done recently.
- JICA expert team as a technical transfer component established manuals that will be used in the planning, design, procurement and monitoring of the biogas system.

Table of Contents

Part-1 Guideline for Biogas Generation System Planning

Part-1 Guideline for Biogas Generation System Planning

SUMMARY of BASIC PLANNING

- Basic planning is conducted to figure out the scale of system, overall demand, possible energy supply and the initial cost of the project.
- Project objective, availability of feedstock, amount of biogas production, benefit from fuel or electricity saving, demand assessment, determination of the system layout, design and cost estimation is done at this stage.
- Objective of the of the project: this is the most important step in planning.
- Availability of feedstock: feedstock that is available is calculated to determine the amount expected daily.

L1-2-2

SUMMARY of BASIC PLANNING CONT…….

- Amount of biogas production: in m^3 per kg of feedstock is calculated. The value is variable according to weight and feeding conditions.
- Benefit from fuel or electricity: amount of fuel wood or other fuel saved by biogas and the amount of energy generated by the produced biogas is calculated.
- Demand assessment: in the facility is ascertained.
- System layout: this is site specific and depends on the general slope and effluent management plan.

Attachment L-1-2

Part-1: 4.2 Energy production and demand Amount of biogas production-- Human

Description	Value	Unit
Amount of biogas production [1]	0.02-0.028	m^3/person/day
Size of digester	0.1	m^3/person
Substrate	3.3-4.9	L/person/day
faeces	0.25-0.4	kg/person/day
urine	1-1.5	L/person/day
flushing water	2-3	L/person/day

1) Biogas as an alternative to fuelwood for a household in Uleppi sub-country in Uganda

$$V_h = 0.024 N_h \times O \times D \times R$$

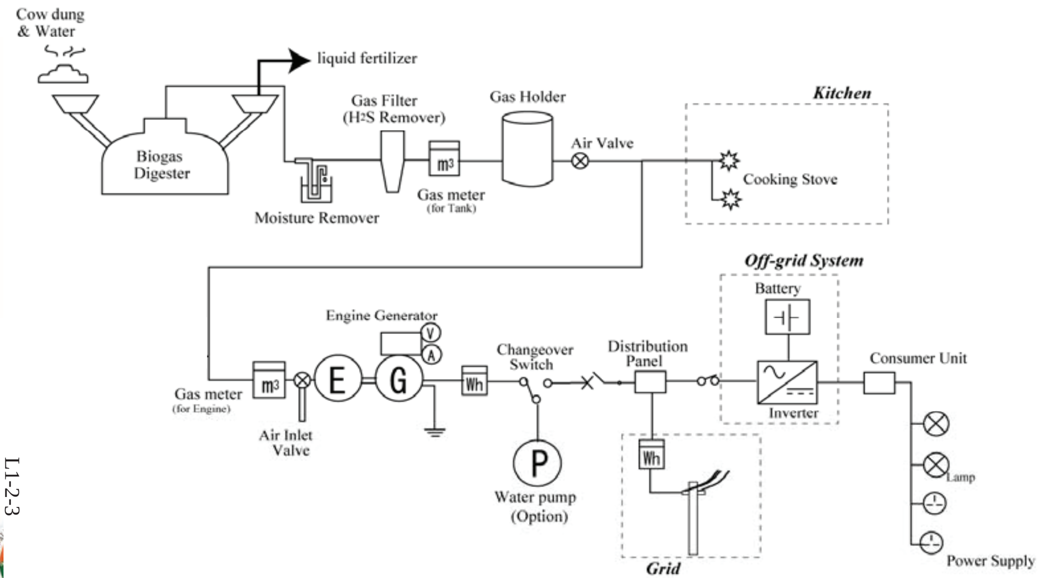
Where, V_h: Volume of biogas production from human waste (m^3/year)
N_h: Number of persons utilizing toilets connected to the digester at the facility
O: Body weight ratio, average weight of persons/average weight of adults
D: Number of regular days (= 365 – number of long holidays))
R: Toilet usage ratio (percentage of toilet use connected to the digester)

Example:
0.024 m^3/person/day x 1000 students x 0.8 x (365-92) x 0.75 x= 3942 m^3/year

BASIC PLANNING CONT………….

- Design: determination of the digester size and the type to be used in a particular area. Pipe line length, biogas engine (electricity) and stove (thermal) application.
- Cost estimation: includes labour transportation, material, administration, testing and commissioning, user training and documentation.
- Financial and economic evaluation is also calculated.

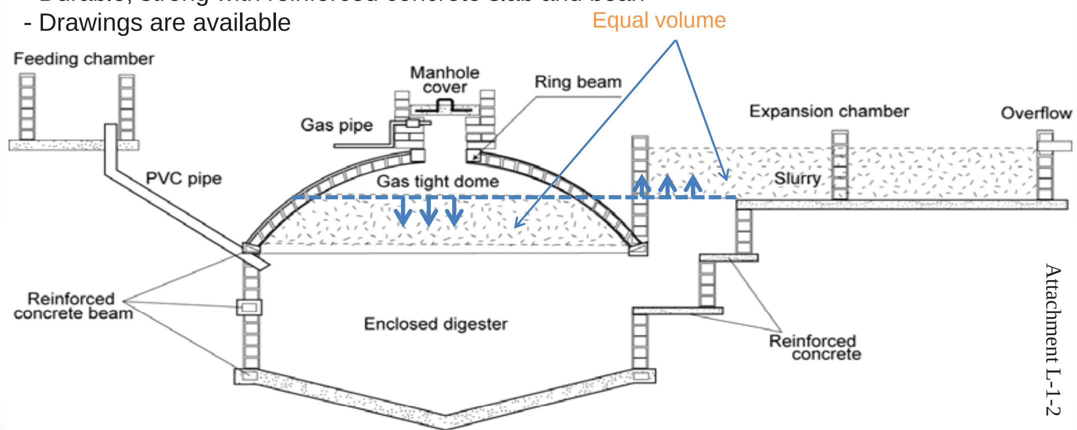
Part-1: 5.1 Biogas Generation System



L1-2-3

Part-1: 5.2.3 Design of Biogas Digester

AKUT Type Digester, Biogas Construction Manual, prepared by GmbH, and PSDA
- Cone bottom shape digester with feeding chamber and expansion chamber
- For toilet connected digester, inlet and outlet pipe is connected to sewer line
- Durable, strong with reinforced concrete slab and bean
- Drawings are available



Attachment L-1-2

Source: AKUT Type Digester, Biogas Construction Manual, PSDA/GIZ

Part-1 Guideline for Biogas Generation System Planning

PROCUREMENT

- Procurement is done in accordance with the Public Procurement and Disposal Act 2006. The method consists mainly of open tender.
- The bidding document is prepared by the procuring entity (Rural Electrification Authority). All eligible bidders obtain it from the company website and submit the duly filled document to the offices.
- The bids are subjected to an evaluation process, and the successful bidders are awarded contracts to carry out the project.
- REA supervisors monitor the construction of the project and the commissioning activity.
- Contractors are paid at when completed works are satisfactory.

Part-2 User Guideline for Biogas Generation Operation

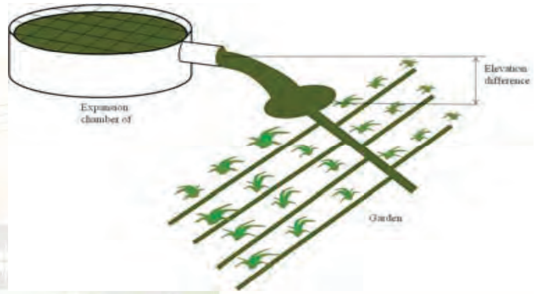
L1-2-4

Part2: 3. Operation and Maintenance

-Daily operation : water& urine mixing

Item	Dry cow	Lactating caw
Body Weight (kg)	612 ±70	614 ±47
Water intake (kg/day)	28.0 ± 9.1	98.4 ±14.9
Urine amount (kg/day)	10.8 ±4.9	21.9 ±7.5

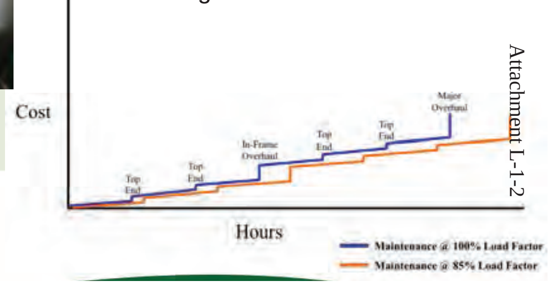
- Utilization of effluent



- Biogas pressure measurement

Digestor Size m^3	Dung/day kg	Nos of Cow	Gas production m^3	Max Pressure (cm) (mbar)
8	100	5	3	94
12	150	7	4.5	97
16	200	9	6	105
24	300	13	9	115
32	400	17	12	125
48	600	25	18	125
59	740	31	22	127
71	900	38	28	133
80	1100	46	34	135
124	1500	63	46	140

- Engine maintenance



Attachment L-1-2

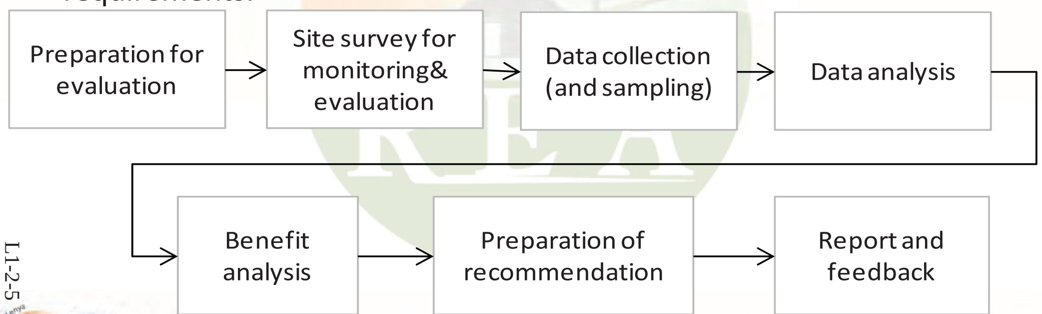
Part-3 Guideline for Monitoring and Evaluation

Part-3: 1. Monitoring

Item	Unit	Description	Frequency
Biogas Production amount	m^3	Biogas production amount. Measured by gas flow meter.	Every day
Generated Energy	kWh	Energy amount generated by biogas generator. Measured by energy meter.	Every day
Energy Output	kW	Power output by biogas generator. Measured by biogas generator indication.	Every day
Temperature	ºC	Ambient temperature. Complementary information to assess gas production efficiency.	Every day
pH	-	Potential of hydrogen. This is the indication of acidity and alkalinity condition inside a biogas digester and slurry. Optimal pH is 7-8.5.	Occasional monitoring
Methane concentration	%	Percentage of Methane in biogas. This is the indication of biogas production.	Occasional monitoring
ORP	mV	Oxidation Redox Potential. This is the indication of anaerobic condition of biogas digester.	Occasional monitoring
Biogas analysis (detailed)	-	Gas is sampled and sent to a laboratory. Concentration of components is analyzed by gas chromatography (CH_4, CO_2, O_2, N_2, H_2. etc.)	When required for study and R&D purpose

Part-3: 2. Evaluation

- To analyze system efficiency
- To obtain lessons and learn from them for implementation of similar projects in future
- To provide advice for better and more efficient operation
- Especially for public projects, it is necessary to present data and analysis results to justify the project according to accountability requirements.



L1-2-5

REA's Biogas projects

REA has successfully completed a biogas project in Mangu high school. Generating electricity from the biogas obtained which is used to pump water. Isinya biogas will undergo rehabilitation to begin functioning. Feasibility plan for construction of another facility in Nyeri high school is underway.

Attachment L-1-2

Conclusion

The development of a guideline manual in biogas generation is a big step towards the development and promotion of the technology.

Your comment on the draft guideline is appreciated by 13 November 2014.

Rural Electrification Authority

Lighting up rural Kenya

THANK YOU

Rural Electrification Authority

Lighting up rural Kenya