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Sustainable Energy Generation from Biogas through Integrated Waste Management in Public Buildings

(A Case Study of Waziri Umaru Federal Polytechnic Birnin Kebbi, Kebbi State Nigeria)

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Abstract **Review Article**

The biogas is a renewable energy source predominantly composed of carbon dioxide and methane, generated by the decomposition of organic materials including solid municipal waste, agricultural waste, animal waste, plant matter, sewage, food scraps and green trashes. It serves as a clean energy option, yielding both methane gas and liquid fertilizer as its principal by-products. In this study, 200 kilograms of fresh cow dung collected from Abature in Birnin Kebbi were mixed with 1,000 litres of clean water and fed into a bio digester with a 2,000-liter capacity.

The bio digester system was equipped with a 2 m³/psi gas tube, inlet and outlet pipes each 100 mm in diameter and 6 bar thick, two gas valves (100 mm), eight 100 mm PVC connectors, four rubber nipples (100 mm), a 0.5-meter flexible steel pipe, a 3-meter PVC flexible polyester gas pipe, 10 kg of resin and hardener adhesive, a 60-inch hose pipe, a gas pressure gauge, clips, screws, construction materials (blocks, sand, cement, stones), and a three-stage gas filtration system using chlorine, calcium, and sodium oxide.

The fermentation occurred in an oxygen-free (anaerobic) setting over a 60-day period, resulting in the generation of 10 m³ psi of raw methane gas. This gas was utilized for cooking using a 2 m³ capacity gas burner for a total of 20 hours. The project demonstrates the "waste-to-energy" principle by addressing key sustainability issues: it reduces environmental pollution, transforms waste into valuable energy (biogas), and creates liquid bio fertilizer via anaerobic digestion. Implementing such waste management solutions in public institutions can notably cut greenhouse gas emissions, lower expenses related to cooking fuel and agricultural fertilizers, and support healthier communities. The experiment was carried out at Waziri Umaru Federal Polytechnic, located in Birnin Kebbi, Kebbi State, Nigeria.

Keywords: waste management, energy production, biogas (clean methane).

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INTRODUCTION

The Kebbi Kingdom was initially founded in 1515 AD by Muhammad Kanta in Suraye. By the seventeenth century, political activities in the kingdom had shifted to Birnin Kebbi (12.43180° N, 4.19560° E), under the rule of Sarkin Kabi Tommo. Today, Birnin Kebbi functions as the capital of Kebbi State and the administrative centre of the Gwandu Emirate in Northwest, Nigeria, was carved out of Sokoto State on August 27, 1991. Its neighbors include the Republic of Benin to the southwest, the Dosso Region of the Niger Republic to the west, Zamfara State to the east, Sokoto State to the north, and Niger State to the south (Mukhtar, 2016).

Animal waste, which includes blood from slaughterhouses and by-products of meat processing, is one of several waste streams of concern. Globally, energy which is vital for economic progress is derived from both renewable and non-renewable sources, including wind, sun, and biomass, as well as coal, oil, and nuclear power. Fossil fuels continue to be the predominant source, representing more than 80% of the world's energy use, with detrimental effects on the environment (Duerr, Cruden & McDonald, 2018). Nigeria, despite being rich in energy resources and holding the tenth largest crude oil reserves globally (approximately 4.896 billion tons or 36 billion barrels, in 2016), has not yet succeeded in achieving sustainable growth.

The global push for environmental preservation, sustainable energy, and eco-conscious waste management has driven interest in renewable energy and energy efficiency. Embracing circular economy principles through the anaerobic breakdown of organic municipal garbage can yield significant ecological and economic benefits via gas and liquid by-products (Abad, Avila, Vincent & Front, 2019).

Nigeria, as Africa's most populous nation, generates large quantities regarding organic waste due to agricultural practices, industrialization, and urbanization resulting in increasing pollution of the environment. Waste generation continues to rise, and there is growing emphasis on efficient disposal strategies. Although the waste-to-energy (WTE) concept has gained recognition as an environmentally friendly strategy (Akhator, Obanor & Ugege, 2017). Its adoption remains limited. The WTE model is aligned with the "Four Rs": reduce, reuse, recycle, and renewable energy (Kothari, 2014). Compared to landfilling and incineration, WTE technologies offer superior alternatives by producing renewable energy and beneficial by-products like biogas and organic fertilizers (Kothari et al., 2008).

Waste typically accumulates in solid, liquid, and gaseous forms. Effective waste management entails its compilation, transportation, treatment and recycling, resource recovery and ultimate disposal (Okey, Umana, Markson & Okey, 2013). Poorly managed waste leads to pollution, necessitating the use of effective waste reduction and recycling strategies to maintain urban cleanliness (Dauda & Osita, 2009). Municipal trash management in many underdeveloped nations, such as Nigeria, mostly consists of straightforward collection and disposal with little resource recovery (Okey et al., 2013). WTE becomes most relevant during the period of resource recovery (Akhator et al., 2017), providing a remedy to reduce fossil fuel use and strengthen energy security (Abubakar & Ismail, 2012).

Adoption of WTE requires evaluating factors such as feasibility, public acceptance, education, infrastructure, cost, pollution risk, greenhouse gas emissions, land use, and technological capacity. WTE technologies can reduce waste volume by up to 90% while recovering metals and energy, depending on its composition from municipal solid waste (Voelker, 2004; Kathiravale, 2008; Wang, 2009; Kothari et al., 2013). However, developing countries like Nigeria still face critical challenges due to the absence of engineered landfills, bioreactors, and large-scale anaerobic digestion (AD) facilities. As a result, valuable waste resources are lost through indiscriminate dumping, causing environmental deterioration (Duerr et al., 2018).

This study explores the possibility of solid waste in abattoirs in Birnin Kebbi, as an anaerobic source of microorganisms for biogas production.

LITERATURE REVIEW

Current Practices and Solid Waste Management Issues in Nigeria

The progressive removal of cesspools and septic tanks for sewage management in Africa is largely due to the environmental consequences associated with the improper disposal of untreated sludge. These traditional systems have become major contributors to land-based pollution, posing risks to public health and sanitation. The average cost of sewage evacuation ranges from ₦50,000 to ₦100,000 per trip, which can negatively impact the value of affected properties. In cases where Sewage Treatment Plants (STPs) exist, their limited capacity requires consistent electricity and incurs high maintenance expenses, rendering them economically unsustainable over time (Lincoln, 2019).

Adelakun (2002) defines biogas as a fuel generated from anaerobic decomposition of natural materials like human waste, animal manure, plant residues and kitchen scraps without oxygen. This gas produced through biological activity, is categorized as a biofuel, the kind of secondary sustainable energy derived via thermochemical or biochemical conversion of carbon-rich biomass. The primary materials used in biogas production include:

i. Manure (e.g., human excreta or cow manure)
ii. Municipal garbage
iii. Waste from green plants
iv. Waste water (Sewage)
v. Debris from agriculture

Methane (CH_4) and carbon dioxide (CO_2) are the main components of biogas, with traces of siloxanes, dampness, and hydrogen sulfide (H_2S). It is possible for gases like carbon monoxide (CO), hydrogen, and methane to burn in the presence of oxygen to release energy, making biogas a versatile fuel source. In Nigeria, it can serve multiple purposes, including cooking, electricity generation, and heating through anaerobic digestion systems. When compressed, biogas can power vehicles similarly to natural gas. For instance, the UK estimates that biogas could potentially replace up to 17% of its vehicle fuel. As a renewable resource, biogas qualifies for clean energy incentives in various regions and holds significant promise for broader application in Nigeria. Once purified, additionally, it can be improved to meet standards for natural gas, resulting in methane bio-based (Folarin, 2008).

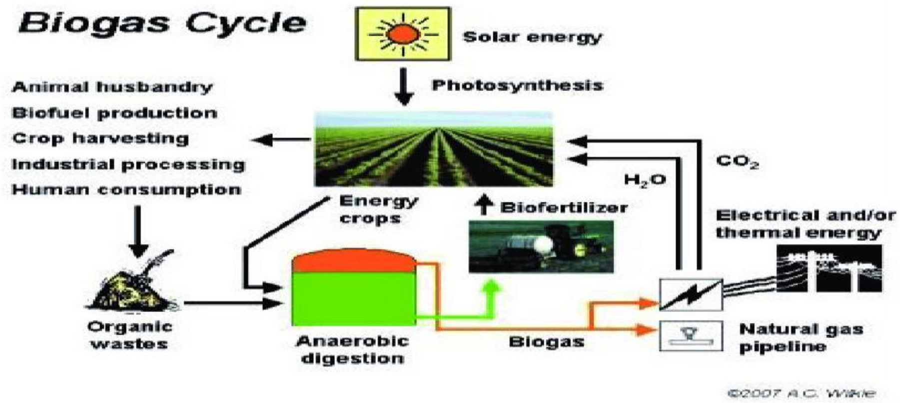


Figure 1: Depicts the biogas production cycle, detailing the origins of organic waste and the subsequent applications of the resulting biogas

Organic Waste Generation in Birnin Kebbi, Kebbi State

A comprehensive understanding of organic waste is crucial for effective biogas production. Organic waste comprises biodegradable materials originating from plants or animals, which decompose rapidly due to bacterial activity. These materials break down into natural elements such as carbon, which re-enter the ecological cycle (Encarta Dictionaries, 2009).

Types of Solid Waste Produced in the Birnin Kebbi Abattoir

Several categories of organic waste are present in this area:

i. Human Waste: This includes excreta from the human digestive system—urine, feces, menstrual discharge, and other metabolic by-products.

ii. Agro-Industrial Waste: Waste from industries that process food, such as vegetable residues, fruit and waste from the canteen is highly organic and has strong potential for methane production (Ezekoye, 2006).

iii. Green Waste: This comprises seasonal waste from communal activities like grass cutting and leaf collection.

iv. Sludge from Wastewater Treatment: This includes both primary and secondary sludge.

v. Grease Waste: Sourced from restaurant grease traps, these wastes are also high in methane potential (Okeke, 2011).

Other examples of organic waste include paper towels, ruined food in the refrigerator, rice, beans, cheese, bones, and eggshells and similar materials.

Environmental Impacts of Organic Waste

According to Song (2004), organic waste can have both beneficial and harmful effects on the environment, influencing both living (biotic) and non-living (abiotic) components:

i. Soil and Water Contamination: Waste compacted in landfills undergoes anaerobic decomposition, producing acidic compounds. Other waste items, such as plastics, interact with these acids, forming hazardous liquid called leachate. This toxic liquid often seeps into groundwater and eventually contaminates rivers and streams.

ii. Limited Landfill Capacity: Landfills are filling up rapidly, and since organic waste accounts for nearly half of household waste, composting provides a sustainable substitute. Composting converts trash into valuable nutrients soil, reducing landfill pressure and environmental pollution.

iii. Greenhouse Gas Emissions: Organic waste in landfills emits methane and carbon dioxide two potent greenhouse gases. Methane, which makes up around 54% of landfill gas, is 24 times more harmful than carbon dioxide (40%) in terms of global warming potential. These emissions significantly contribute to climate change, affecting agriculture and public health (Tower Lombard et al., 2012).

Advantages of Composting

i. Enhances water draining clay soils and improves the retention of moisture in sandy soils (Tower, 2012).

ii. Promotes healthier plant growth and increases resistance to diseases.

iii. Helps take in and filter and filter stormwater runoff, preventing pollution and erosion in river.

iv. Lowers the presence of pests, thereby decreasing the need for chemical herbicides and pesticides, which can contaminate water systems (Wilkie, 2004).

v. Minimizes the effort and cost of disposing garden waste by eliminating the need for curbside collection or landfill transport.

Constituents of Human Solid Waste

Table 1 presents the constituents of human solid waste.

Materials	Faeces (%)	Urine (%)
Amount	150-300 g/person/day	1-1.3 l/person/day
Moisture Content	66-80	93-96
Dry matter	40-81 g/person/day	50-70 g/person/day
In the dry matter:Organic compound	88-97	65-85
N	5-7	15-19
P (as P_2O_5)	3-5.4	2.5-5
K (as K_2O)	1-2.5	3.0-4.5
C	40-55	11-1.7
Ca (as CaO)	4-5	4.5-6

Table 1: Composition profile of human-generated solid waste

Washington D.C. has initiated a plan to generate biogas from sewage sludge, a residual product of sewage treatment, which is projected to result in annual savings of $13 million. In 2015, teams from the Cambridge Development Initiative, under the leadership of Stanford researcher Maisam Pyarali, launched a project in Dar es Salaam's informal settlements to transform sewage into biogas and fertilizer using solar concentrators. As reported by Khan, Izhan et al. (2019), it is possible to produce approximately a single cubic foot of gas from each pound of cow manure at about 28 degrees Celsius (28°C).

THE BIOMASS

The Biomass refers to any form of natural material such as Seaweed, wood, vegetables, and animal waste that can be converted into energy resource. Most likely the earliest energy source utilized by humans following solar energy. For millennia, people have burned wood for heating and cooking purposes (Lincoln, 2019). Biomass derives its energy from sunlight, as all organic material stores solar energy. Sunlight allows plants to produce sugars and oxygen from carbon dioxide and water through a process called photosynthesis. Carbohydrates are the sugars that power plants and the animals that eat them. Carbohydrate-rich foods are a valuable energy source for humans (Kwon, 2004). Biomass qualifies a sustainable energy source due to its supply is continuous, we can continually cultivate crops and trees, and organic waste will always be generated (Wilkie, 2003).

Categories of Biomass

There are four principal categories of biomass currently in use: agricultural waste and wood, landfill gas, solid trash and alcohol-based fuels.

i. Agricultural Waste and Wood

Currently, majority of biomass energy originates from what is known as "homegrown energy". Logs, chips, bark, and sawdust make up around 49% of the energy obtained from biomass. However, various forms of organic material can be harnessed for this purpose. Other sources of biomass are agricultural waste, such as corn cobs and apple pits. These, in conjunction with wood waste are commonly used to generate energy most often by the industries that produce them. Such electricity is usually not part of public utility supply but is cogenerated, meaning it's consumed onsite. For example, paper and sawmills often convert their own waste into steam and electricity. Despite this, they still often need to supplement their energy needs from utility companies (Boum, 2011). Timber and wood product industries are increasingly recognizing the economic advantages of using sawdust and wood scraps for energy production, helping them reduce waste disposal costs and lower their energy bills. Indeed, the pulp and paper sector now satisfy about half of its energy needs using biomass. Other sectors employing biomass include producers of furniture and agricultural enterprises (nut and rice producers) and alcohol distilleries.

ii. Landfill Gas

Landfill gas arises from microbial activity that breaks down organic waste in engineered landfill sites often resembling bowl-shaped stadiums designed to isolate waste from the surrounding environment, especially groundwater. As microbes such as bacteria and fungi consume decomposing organic material, they produce gases including methane, even under the slow, oxygen-deprived conditions of a landfill (Wolly, 2011). Methane is invisible and odorless, but highly flammable, posing risks of fires or explosions if it leaks into nearby buildings. Regulations now mandate the capture of methane from landfills for safety and environmental concerns. Once collected and purified, methane a significant component of natural gas, is a useful energy source for cooking and heating. East Kentucky Power Cooperative started using methane from three landfills in 2003 and finally produced 16 megawatts of electricity, which is enough to power between 7,500 and 8,000 houses.

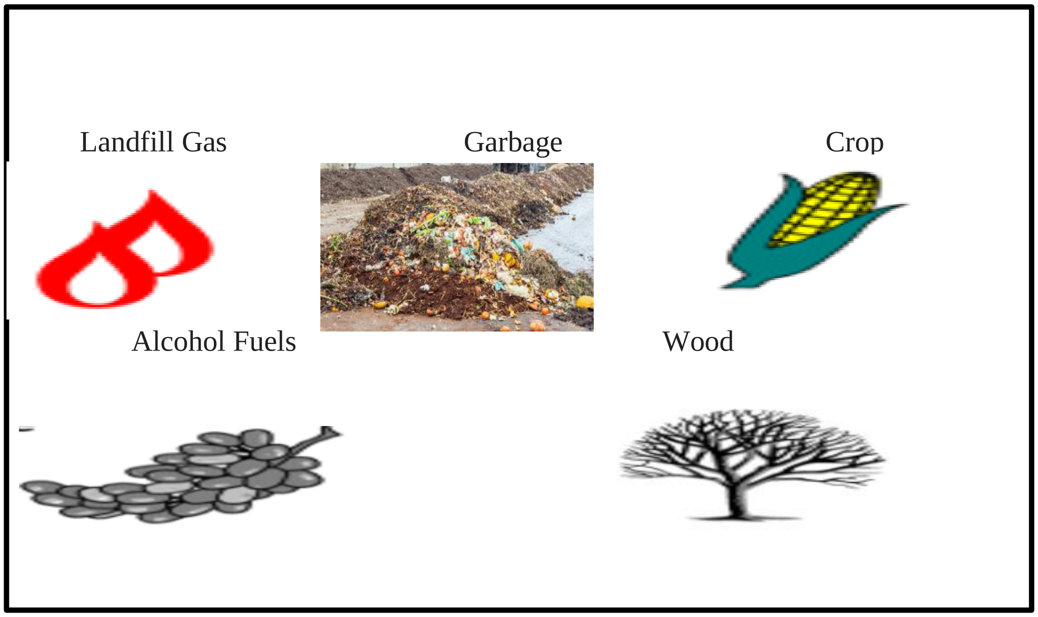
Utilizing methane is still advantageous even if only a small portion of landfill gas is being used for energy, and the majority is flared since recovery is not profitable due to low natural gas prices. Carbon dioxide is a far weaker greenhouse gas than methane, thus burning it to produce CO_2 lessens its effects on the climate. Methane can also be intentionally produced through anaerobic digestion in airtight bio-digesters made of steel or brick, using animal or human waste. This fermentation process produces a methane-rich biogas suitable for cooking, lighting, and even electricity production. The resultant gas burns cleanly, producing no smoke and very little carbon monoxide. Individual families or entire communities can benefit from the low-cost, low-maintenance bio-digesters. They operate effectively in moist environments with moderate temperatures. In developing regions, biogas systems could play a critical role in reducing deforestation, lowering air pollution, enhancing soil fertility, and delivering safe, sustainable energy to rural populations (Okeke, 2006).

iii. Solid Trash

Converting waste into energy by burning it allows waste to become a practical energy source. The energy contained in one ton (2,000 pounds) of trash is equivalent to 500 pounds of coal. Although not all waste may be classified as biomass because plastics derived from petroleum account for almost half of its energy content, it can still be incinerated in waste-to-energy plants. These facilities operate similarly to coal-fired power stations but utilize combustible waste as fuel. Although electricity from trash tends to be more expensive than that generated from coal or other sources, the primary benefit lies in significantly reducing landfill waste by up to 60–90%. This reduces landfill-related costs and recovers some energy from materials that would otherwise decompose unused.

TYPES OF BIOMASS

Figure 2: Below illustrates examples of biomass utilized as raw materials in biogas production



Biomass Energy Usage

The burning of wood and wood waste, such as sawdust, provides over half of the biomass consumed today. Over one-third is derived from biofuels mainly ethanol which is commonly blended with gasoline. The remainder originates from crops, waste materials, and landfill gases. Industry is the largest consumer of biomass, utilizing more than 51% of it. About 11% is used by electric utilities to generate power, although biomass accounts for only 0.7% of total electricity production. The transportation sector follows, consuming around 24% of biomass to produce ethanol and biodiesel. Residential users account for another 11% of biomass usage.

Advantages of Biomass Energy

While wood is traditionally burned for heating, there are several ways to convert biomass into useful energy:

i. Fermentation: Ethanol is produced from plant materials like corn through fermentation, typically using yeast to convert plant starches into alcohol. Recent advancements now allow enzymes to break down plant cellulose, increasing ethanol yields by using the entire plant.

ii. Combustion: Biomass can be incinerated from waste to energy facilities to generate steam for electricity or to supply heat for homes and industries.

iii. Decomposition of Bacterial: Organic waste breaks down with the help of bacteria, releasing methane a primary component of natural gas. Many landfills are capturing and utilizing this methane for energy.

iv. Conversion of Chemicals and Heat: Biomass can also be converted into gaseous or liquid fuels using heat or chemical treatments. For example, cow manure in India is processed to generate methane, which can be converted into methanol for energy production.

Environmental Impact of Biomass

Compared to fossil fuels like coal and oil, biomass offers several environmental benefits. It contains minimal sulfur and nitrogen, reducing the risk of acid rain. Additionally, growing biomass crops may help maintain atmospheric carbon dioxide balance, as plants absorb CO_2 during growth.

Sources of Renewable Energy

Renewable energy is produced using naturally occurring resources including geothermal heat, wind, water, tides, and sunlight. As of recent reports, approximately 16% of the world's ultimate energy consumption comes from renewable sources. 10% comes from traditional biomass, primarily for heating, and 3.4% comes from hydroelectricity. An additional 3% is made up of emerging renewables that are growing quickly, such as wind, solar, geothermal, and biofuels.

About 19% of global electricity is produced by renewables, with 16% coming from hydropower and 3% from other sources. Especially in Europe, Asia, and the United States, wind energy is expanding at a 30% annual pace and is expected to reach 238 gigawatts of installed capacity by the end of 2011. 67 gigawatts of photovoltaic (PV) capacity were installed worldwide in 2011, with Germany and Italy hosting the largest installations. The SEGS facility in the Mojave Desert (354 MW) is the largest of several solar thermal plants that are in operation in nations including the United States and Spain. The largest geothermal site in the world, with a 750 MW capacity, is the Geysers in California.

Brazil is a leader in the manufacturing of biofuels; 18% of its automobile fuel is made from sugarcane ethanol. In the US, ethanol is also widely used. Even though a lot of renewable energy projects are big, technologies like advanced biomass stoves, micro-hydro setups, small solar PV systems, and home-scale methane digesters are empowering millions of people in rural and off-grid areas.

United Nations Secretary-General António Guterres emphasized that renewable energy can significantly enhance economic prospects for the world’s poorest communities.

The Future of Renewable Energy

Concerns over climate change, rising oil costs, and supportive governmental policies are driving rapid advancements in renewable energy development. Legislative incentives and investments have enabled the sector to remain resilient, even during global financial downturns. The International Energy Agency predicted in 2011 that solar energy might overtake all other electricity sources in the globe within 50 years, significantly lowering greenhouse gas emissions and improving the environment (Adelekan, 2002).

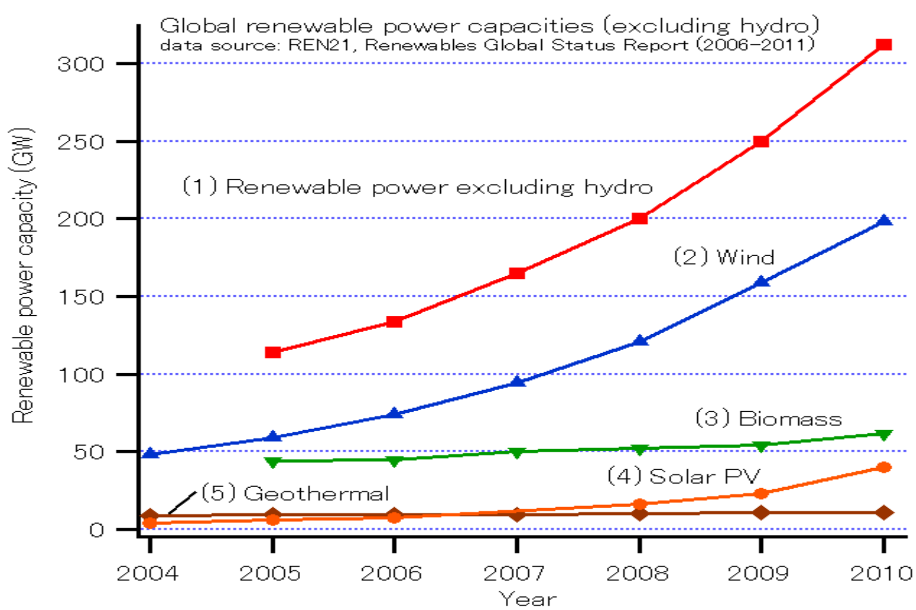


Figure 3: Global Capacity for Renewable Power (Adelekan, 2002).

Overview of Renewable Energy

Renewable energy sources are fueled by naturally occurring processes such geothermal heat, wind, sunlight, vegetation growth, and ocean tides. The International Energy Agency claims that natural processes constantly replenish renewable energy. These energy forms primarily originate from solar radiation or geothermal heat from beneath the Earth's surface. This category includes heat and power produced by geothermal, hydropower, biomass, wind, solar, and ocean currents, as well as hydrogen and biofuels made from renewable resources. (Renewables, 2010).

Globally, renewable sources account for approximately 19% of electricity production. These sources are utilized across numerous nations, with wind energy alone contributing significantly in some regions. For instance, In Iowa (USA), Schleswig-Holstein (Germany), and Denmark, it supplies 14%, 40%, and 20% of the electricity, respectively. Norway (98%), Brazil (86%), Austria (62%), New Zealand (65%), Sweden (54%), Iceland and Paraguay (100%), and other countries get almost all of their electricity from renewable sources (Renewables, 2010).

A key component of renewable heat is solar water heating, particularly in China, which has 70% of the world's capacity (180 GWth). An estimated 50–60 million households receive hot water from these systems, which are primarily installed in residential apartment complexes. Over 70 million households worldwide rely on solar thermal systems to meet their hot water demands. Sweden is already using more biomass energy than oil, and the use of biomass for heating is still growing. Additionally, direct geothermal heating is expanding rapidly.

Since 2006, biofuels have produced a considerable reduction in the amount of oil used in the transportation sector in the United States. An estimated 68 billion litres of gasoline were replaced by biofuels worldwide by 2009, reaching 93 billion litres, or around 5% of total gasoline production (Schievano et al., 2010).

Primary Types of Sustainable Energy

i. Solar Energy
ii. Wind Energy
iii. Hydropower
iv. Geothermal Energy
v. Biomass
vi. Biofuels

Non-Sustainable Resources

Non-sustainable resources are natural assets that are not regenerated or replenished at a rate that matches their consumption. Once exhausted, they cannot be restored for future use. These include materials that are depleted faster than nature can replace them. Fossil fuels are an example of non-renewable resources (natural gas, oil, and coal), uranium used in nuclear power, and some groundwater aquifers.

Conversely, resources like sustainably harvested wood and recyclable metals can be considered renewable. Coal, crude oil, and natural gas are examples of fossil fuels that take millennia to create and cannot be replenished at a rate that keeps up with their consumption. Over time, these resources will become economically impractical to extract, prompting the need for alternative energy sources (McClain et al., 2017).

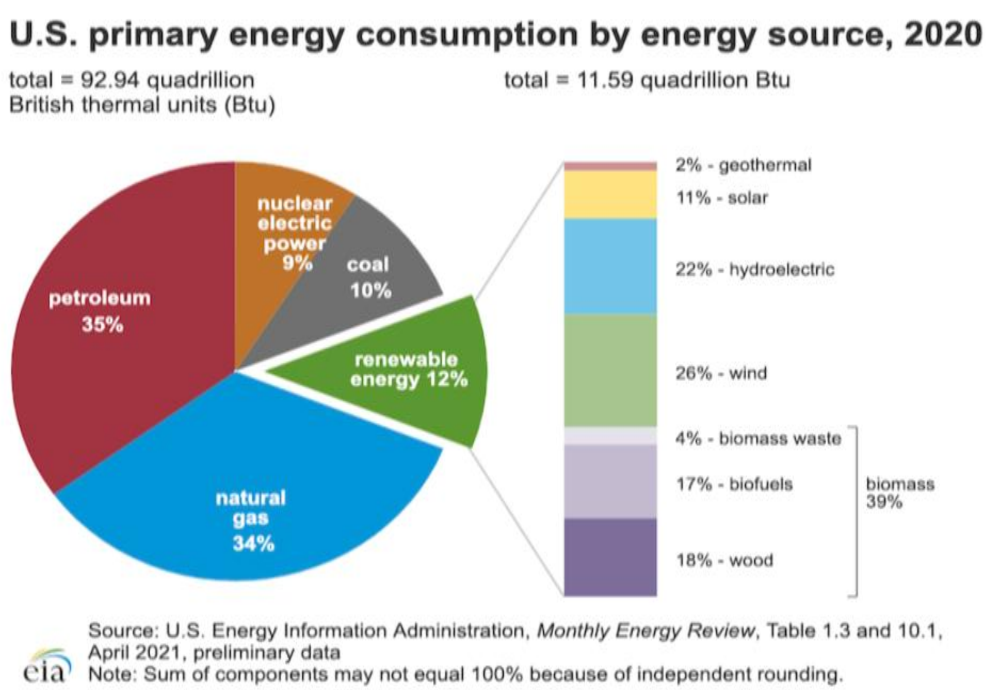


Figure 3: Examples of the Sources of Energy. (www.wikipedia.org)

Biogas Production

Biogas is a gaseous fuel primarily made up of 50–70% methane (CH_4) and 30–50% carbon dioxide (CO_2), with smaller amounts of water vapor, hydrogen (H_2), oxygen (O_2), hydrogen sulfide (H_2S), and nitrogen (N_2). It is created by the anaerobic breakdown of organic molecules. For the production of biogas efficiently. three (3) different groups of microorganisms need to work together harmoniously. If too much organic matter is added, the first two microbial groups might produce too many organic acids, which would lower the pH of the reactor. This acidic environment inhibits the third microbial group, thereby hindering or halting gas production. Conversely, insufficient organic waste limits microbial activity and significantly reduces biogas output. While moderate mixing in the reactor can enhance digestion, excessive agitation can have a negative effect and lower biogas yield. Table 2.2 illustrates the amount of biogas generated from different kinds of agricultural and animal waste.

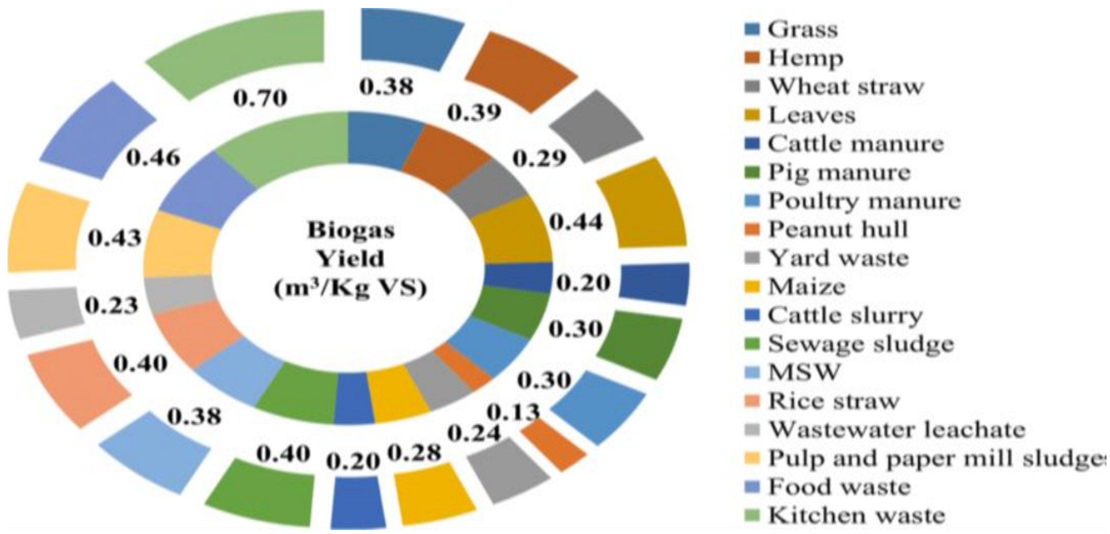


Figure 4: Volume of biogas produced from human faecal matter and agricultural waste

The Process of Anaerobic Digestion

Anaerobic bacteria facilitate the decomposition of organic materials in an oxygen-free environment, a process known as anaerobic digestion (AD). Hydrolysis/liquefaction, acidogenesis, and methanogenesis are the three main stages of this biological process, which consists of a series of metabolic actions performed by various microbial species.

The first group of microorganisms creates enzymes during the hydrolysis phase that break down complex polymers into simpler monomers, such as glucose and amino acids. These monomers are converted into more volatile fatty acids, hydrogen (H_2), and acetic acid by acetogenic bacteria during the ensuing acidogenesis phase. The last stage of methanogenesis is when methanogenic bacteria produce methane (CH_4) from hydrogen, carbon dioxide (CO_2), and acetic acid. According to Lombard (2012), this multi-step process is carried out in sizable digesters (see Figure 2.8), which run at regulated temperatures between 30°C and 65°C.

Figure 5: Anaerobic digester located at the Tilburg facility in the Netherlands.

Hydrolysis/Liquefaction Procedure

In the early phases of anaerobic digestion, hydrolysis or liquefaction occurs. (see Figure 5) fermentative microorganisms break down complex, insoluble organic compounds like cellulose into less complex, soluble materials like fatty acids, carbohydrates, and amino acids. The hydrolytic enzymes that microorganisms release, such as lipases, proteases, cellulases, and amylases, are responsible for this change. Large polymeric structures are broken down by these enzymes into monomers, such as proteins into peptides or amino acids and cellulose into sugars or alcohols. When processing trash with a high organic content, hydrolysis is essential and could be a rate-limiting step. In order to promote methane generation and speed up digestion, certain industrial procedures use chemical additives to increase hydrolysis (RISE-AT, 1998). Hydrolysis reaction examples are include:

i. Fatty Acids → Lipids

ii. Monosaccharides → Polysaccharides

iii. Amino Acids → Proteins

iv. Purines and Pyrimidines → Nucleic Acids

Acetogenesis Procedure

Acetogenesis, the second stage (see Figure 2.9), is the process by which acetogenic or acid-forming bacteria transform hydrolysis products into hydrogen, carbon dioxide, and simpler organic acids. Acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$), and ethanol (C_2H_5OH) are the main byproducts. These transformations are caused by a variety of microbial groupings. For instance, butyrate is broken down by Syntrophomonas wolfei, whereas propionate is broken down by Syntrophobacter wolinii. Actinomyces, Peptococcus anaerobius, and Clostridium species are among the other acid-producing bacteria implicated.

This is an example of an acetogenesis reaction: $2C_2H_5OH + 2CO_2 \rightarrow C_6H_{12}O_6$

Methanogenesis Procedure

Methanogenesis is the last and third step in the process, as shown in Figure 2.9. Here, methanogens, also referred to as methane-forming bacteria, are specialized microorganisms that produce methane. Either acetic acid is broken down to release methane and carbon dioxide, or carbon dioxide is reduced with hydrogen to make methane. Acetate conversion takes over as the primary pathway due to digesters' limited hydrogen supply, even though methane production from CO_2 reduction is more significant (Omstead et al., 2018). Methanobacterium, Methanobacillus, Methanococcus, and Methanosarcina are among the genera that produce methane.

The Methanogens are categorized based on their substrate: either acetate-utilizing or H_2/CO_2-utilizing. Methanosarcina and Methanotrix (also known as Methanosaeta) play crucial roles in anaerobic digestion, functioning in both pathways.

Typical methanogenic reactions are:

i. $CH_3COOH \rightarrow CH_4 + CO_2$

ii. $CH_4 + 2CH_3COOH \rightarrow 2C_2H_5OH + CO_2$

iii. $CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

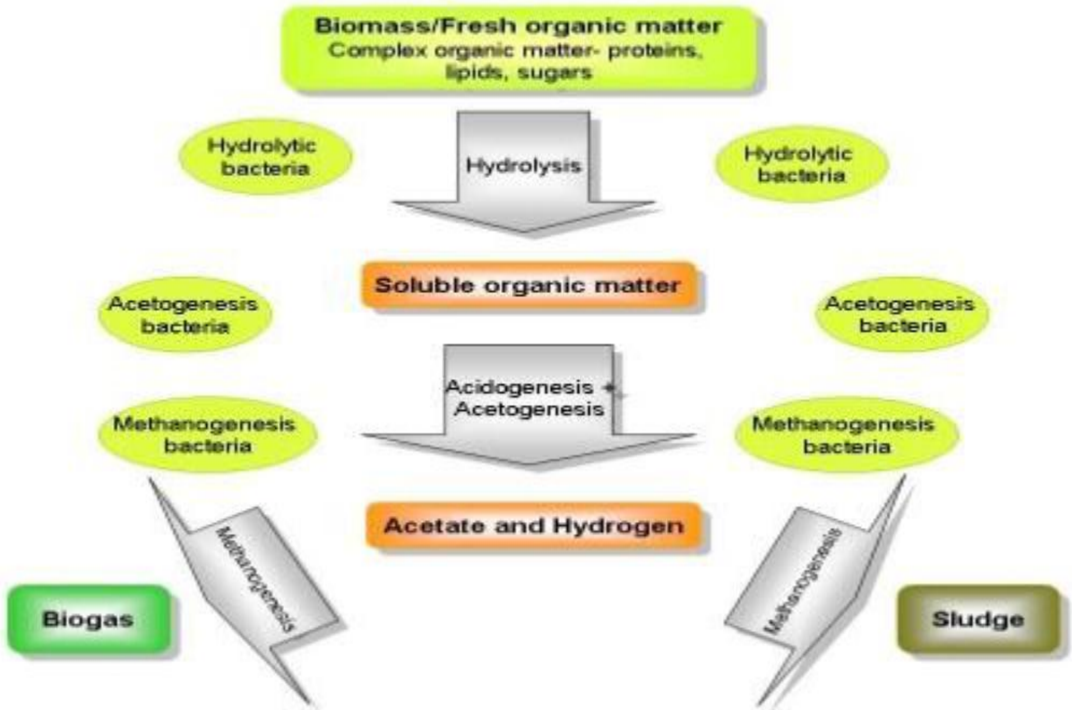


Figure 7: Diagram illustrating the Anaerobic Digestion process. (Naskco Environment, 2009)

Overview of the Anaerobic Digestion Procedure

Pretreatment, waste digestion, gas extraction, and residue treatment are the four primary steps of the anaerobic digestion process. Pre-treatment is necessary in the majority of systems to guarantee uniform feedstock. Shredding the waste and eliminating indigestible materials are the tasks of this stage. Either source separation or mechanical sorting are used to separate the waste before it enters the digester. Separating sources entails removing recyclables like glass, metals, and stones at the origin, while mechanical sorting is used when source separation isn't feasible though this often results in higher contamination and lower compost quality (RISE-AT, 1998).

The trash is first shred before going into the digester, and then it is diluted to get the proper solids content. The digester's own recycled effluent, sewage sludge, or clean water can all be used for the dilution. To keep the digester's interior temperature at the ideal level, a heat exchanger is frequently utilized (see Figure 2.10). The biogas produced during digestion is scrubbed or cleansed to satisfy pipeline quality requirements. As for the residue, the digester effluent undergoes dewatering, with the liquid portion reused for diluting incoming waste. The remaining solids are aerobically stabilized to produce compost (Lincoln, 2019).

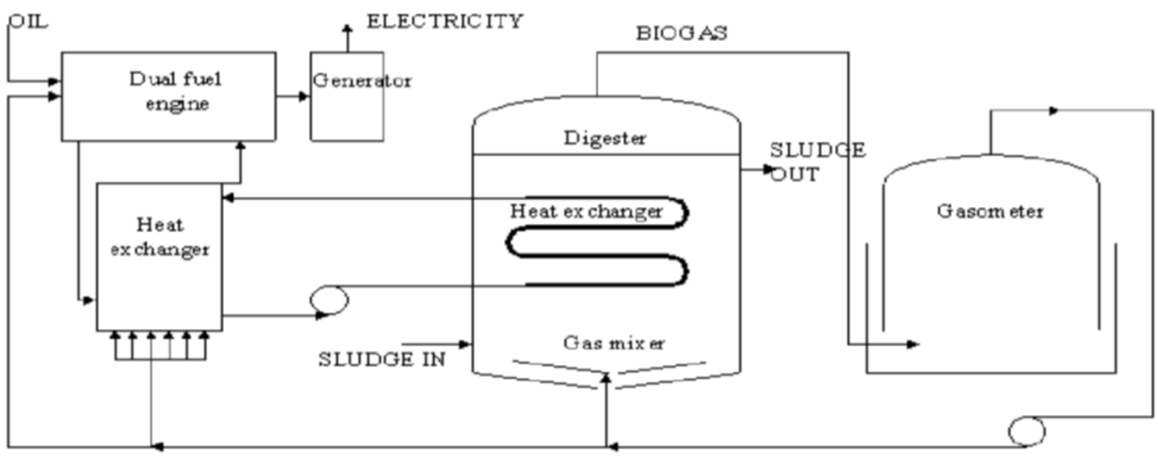


Figure 8: Process flow diagram of anaerobic digestion with low solids content

Advantages of Biogas Technology

Biogas technology provides several key benefits:

i. Energy Production: Biogas can serve as an alternative energy source, taking the place of conventional fuels including electricity, liquefied petroleum gas (LPG), firewood, and petroleum.

ii. Agricultural Enhancement: The slurry byproduct from the biogas digester serves as an organic fertilizer. The organic nitrogen in the waste is converted into ammonia nitrogen, a form that is more readily absorbed by plants.

iii. Environmental Protection: Treating animal waste using biogas systems helps minimize the risk of spreading diseases caused by parasites and harmful bacteria present in raw waste. Additionally, the technology significantly reduces unpleasant odours and fly infestation, and prevents water pollution that often results from improper waste disposal.

METHODOLOGY

The materials employed in this research included constructing a biodigester tank by excavating the ground at an abattoir located in Birnin Kebbi. Other components used were a gas collection airbag, non-return valves, metal adaptors, hosepipes, a four-inch PVC pipe, and organic waste slurry sourced from the abattoir.

List of Materials Used:

i. Animal waste slurry
ii. Gas hose
iii. Gas regulator
iv. Concrete blocks
v. Cement
vi. 4-inch, 6-bar waste pipe
vii. Inner tube (tyre tube)
viii. ½ inch pipe
ix. Gas regulator (duplicate)
x. Adhesives (resin and hardener)

Construction Process

i. Site Selection and Marking: This involves choosing a suitable site for the biodigester and preparing it accordingly.

ii. Excavation: Digging the designated area to the appropriate size for the digester installation.

iii. Block Laying: Building the biodigester walls using concrete blocks to the specified dimensions.

iv. Sealing the Tank: Covering the tank with a precast concrete slab to ensure an airtight system.

v. Fitting Assembly: Connecting the components such as PVC pipes and elbows from the inlet to the digester, routing solid waste from the inspection chamber to the digester. The gas outlet was connected via a ½ inch pipe to a gas regulator for domestic use. Connections were sealed using 4-inch-thick PVC pressure pipes, gas valves, and adhesive.

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

After five days, the biodigester showed noticeable expansion, indicating successful anaerobic digestion without leaks. The produced gas was filtered, observed as bubbles, and collected in a gas tank that expanded, signifying the experiment's success.

Conclusion

i. The biodigester should be installed in areas with sufficient sunlight.

ii. Water testing was conducted to ensure the tank was sealed with no leaks.

iii. Anaerobic digestion took place under airtight conditions in the absence of oxygen.

Recommendations

i. Comprehensive improvements should be implemented in managing biodegradable waste at the abattoir to prevent disease spread and meat contamination.

ii. The biogas system can be scaled up for larger applications, offering financial benefits for effective abattoir operations.

iii. Protective fencing should be installed around the project site to restrict unauthorized access.

iv. Further research is recommended at Waziri Umaru Federal Polytechnic, Birnin Kebbi, focusing on utilizing human biodegradable waste for enhanced renewable energy production.

Project Timeline Overview

The research activities spanned six weeks, covering the entire development lifecycle for constructing a 110m³ biodigester, including the preliminary planning, construction, and finalization phases. A detailed breakdown is provided in the accompanying diagram.

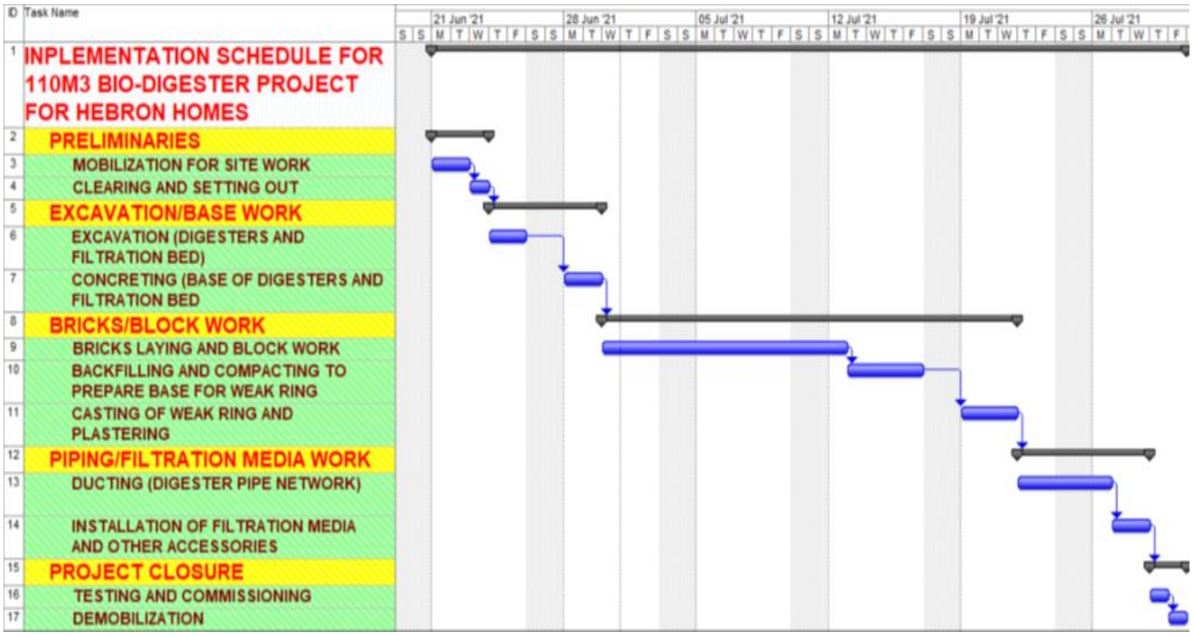


Plate 7, Work schedule for biodigester construction

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Appendix I

The present way of managing waste in Birnin Kebbi abature

Plate 8: Approach view of the abature

Plate 9: Slaughtering room with waste drain

Plate 10: Washed waste channel from slaughtering room to sock away

Plate 11: Soak away pit for slurry waste and water pump for spillage in the abature

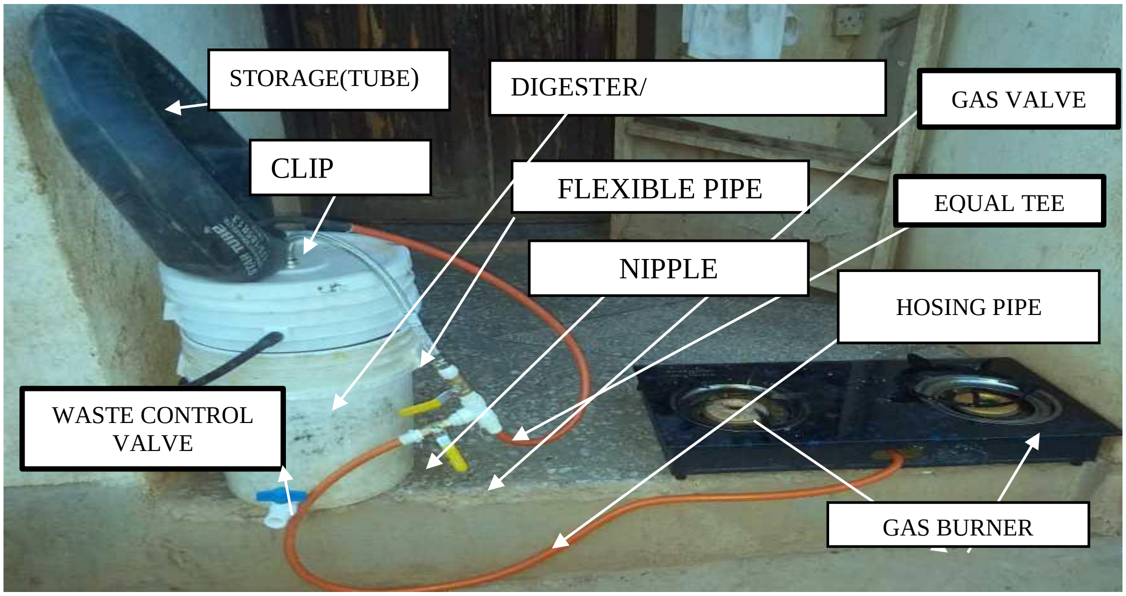

Figure 12, showing the testing process of methane gas generated for cooking.

Appendix II
Plate (13 to 25) Showing tools and materials


Valve


Regulator


Adapter


Tee


Hose Pipe


Water Valve


Clip


Pipe


Nipple


Tube


Bucket


Adhesive


Cow Dung

The processes of constructing biodigester using a 2,000 litter PVC tank.

Plate 26,27,28 and 29: Biodigester tank construction from drilling for inlet, outlet, excavation, placement and backfilling.


Plate 8.


Plate 9.

Plate 10.

Plate 11.

Plate 12, 13, 14, 15 and 16: mixing and feeding the digester, scrubbing and filtering process

Plate 12.

Plate 13.

Plate 14.

Plate 15.

Plate 16.