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Research Article

# A Physical Model for the Sustainable Transformation of Human Waste into Biogas in Housing

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**Abstract:** The study presents the conversion of waste to biogas and its implications for housing development by analysing biogas production approaches and utilisation methods. The study looked at the method of biogas production that is appropriate for generating the incessant operation of biogas schemes in housing, as well as the factors for establishing biogas plants in residential buildings. An experimental variant that includes combinations of liquid human and animal waste compost and houseplant extracts was developed and established to create biogas and increase its yield. The gas engine assessments were carried out for energy applications. The eco-energy arrangement was fabricated by considering the precise housing and local situations. The study takes on one household member in a residential area in Ibadan as a case study, and consequently, the amount of liquid humanoid manure generated was 438 $m^3$/year and 2.4 $m^3$ of biogas was generated per day. The findings indicated that human fluid manure should be aided in producing the essential biogas measure and fuel quality and quantity for the household's energy demand and supply requirements and needs. The study generated a simple biogas application and production method by developing variants and alternatives in which both the waste disposal and the biogas production objectives were accomplished together. The study concluded that for sustainable transformation of human waste into biogas in housing, it is vital to include a biomass plant within the household design scheme, in which biogas plants are in constant operation and biogas is constantly produced for household energy use.

***Keywords*:** physical model, sustainable, transformation, human waste, biogas, housing

## 1. Introduction

The significance of biogas, in addition to the production of fossil fuels, cooking gases, and energy aspects, is vindicated ecologically and globally by the European Union (EU) [1]. These require standardisation and economic and climatic considerations and concerns. The preservation of our surroundings, as well as effective economic sustainability and satisfying energy supply, needs and demands, are paramount in society [2, 3]. This issue can be resolved through the harmonisation of biological waste, the coordinated utilisation and use of recycled organic materials, and the application of renewable, sustainable, and traditional energy sources [4]. It is essential to generate a simple biogas process and an energy utilisation system that are centred on housing development, environmental control, climate consideration, and waste disposal. The hub of the scheme must be combined with environmental energy utilisation and waste management, which are important in a housing development [5].


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Experts in biogas production using waste from animals and residential leftovers have demonstrated numerous significant benefits in addition to being an alternate basis for energy creation [6-9]. This process comprises animal and plant digesters, which offer an alternate terminus for biomass, which would ultimately go unused and be dumped into a trash heap [10]. The use of suitable plant and animal waste digester technical know-how can create energy, and the gas and electricity generated can be utilised for numerous purposes, for example, lighting, space heating, water heating, and cooking in the home [11]. From this perspective, agricultural and residential residues remain one of the best, most common, and most ample energy sources obtainable worldwide [12, 13]. However, the conversion of biological matter to biogas is a multifaceted practise that comprises numerous reactions amid several microorganisms' activities in an established neighbourhood [14].

In the course of selecting a realistic fuel for domestic use, there is a need to take into consideration environmental discipline, which has a character that contains definite areas of energy [15, 16]. Areas of use for biogas include electricity production, cooking, and gas engines, among others [5]. Presently, various efforts and scientific innovations are carried out to reduce energy reliance on petroleum products (oil and gas) [17]. This constraint and prerequisite have led to the development of different technological innovations from other energy sources, for instance, the making of biogas [9]. This biofuel is a significant alternative that guarantees the supply of affordable and clean energy bases, which, if properly handled, will contribute to community development and reduce the accumulation of waste in our society because biomass could be used as a resource for biogas production. Nevertheless, attaining high-quality yields remains a key challenge for domestic use in houses. Household manure is an often-unused potential substrate for biogas production in many developing countries [18].

Studies have shown that household manure contains a lot of water and has a low dry matter content; hence, it is not environmentally or economically advisable to transport it over long distances [12, 13]. Consequently, household manure digestion would have to occur in small-scale digesters. This impelled this potential study in the development of simple, safe, and clean methods that are adjusted and adapted for small-scale household use and applications.

In summary, this study is based on the home biogas process and production that can be created in our residential backyard as a measure of continuing action and innovative research, whereby food waste is turned into renewable energy and sustainable energy practices. Biogas production is a way out of waste management and energy problems. The World Health Organization and the United Nations are currently concerned about climate change and the imminent depletion of fossil fuels, but the benefits and significance of biogas are clear. It is a sustainable and renewable energy source that has no greenhouse gas emissions. With this advantage, its potential has generally gone unexploited, especially in developing countries such as Nigeria. Home-generated biogas is a particularly promising innovative skill that should be exploited, especially with the current global reliance on petroleum products. If encouraged, it will increase national and global green energy development. Limited studies had been undertaken in the area of converting waste to biogas in relation to housing development, especially in a developing country such as Nigeria. The study will provide information on the use of waste in the production of biogas that could be used in the development of housing in Nigeria. Hence, the objective of this study is to examine the waste conversion to biogas, the implications in housing, what effects biogases have on the process of utilisation for domestic usage in residential development from the operation of the cooking gas suitability, and whether utilisation and waste disposal can be achieved together.

## 2. Literature review

Waste-to-gas technology is one of the most environmentally friendly solutions for processing municipal and organic domestic waste, agrarian waste, livestock waste, and ecological and biodegradable waste from any other sources [19]. In this area, Germany seems to be the spearhead in Europe in terms of the number of biogas plants and the quantity of biogas generated, followed by France, Italy, and Austria, while the global leader is China, with the largest number of plants for the production of biogas from waste [9].

Zupančič et al. [1] concentrated on the review and current status of waste-to-biogas transformation, for designated European nations and globally; this study is limited to the area of the significance of waste-to-biogas and its implication in housing. According to studies, the world population is increasing, and the increased population concentration is causing an increase in waste formation, with organic waste amounting to billions of metric tonnes each year. In line with the growing need for recyclable, renewable, and sustainable energy sources, waste-to-biogas transformation is a key model of waste-to-energy technology. This represents a simplistic way to solve problems with gas and electricity production in the home and community [1].

Waste management is one of the fundamental concerns of modern society, and many efforts are dedicated to developing practises to reduce waste buildup in landfills, including waste separation and sorting in developing countries, which make waste recycling and waste disposal cheaper and easier [4]. Additionally, biological waste is generally compostable and can be, as expected, burned and decomposed. Furthermore, waste sludge is created as a by-product of urban and municipal wastewater treatment and needs to be disposed of. Nevertheless, notwithstanding the effective and pronounced drop in waste that culminates and ends up in landfills, the identified conventional methods can have numerous adverse environmental effects, including greenhouse gas emissions in addition to groundwater, air, and soil pollution [10]. One of the most environmentally friendly and appropriate waste management processes is waste-to-gas technology, in which biodegradable waste is converted into biogas through the practise and process of anaerobic digestion. Besides the reduction in carbon dioxide ($CO_2$) emissions and the efficient use of resources, biogas plants also have positive economic impacts and produce environmentally friendly energy. The general acceptance of biogas plants by people is positive, but some preconceptions affect their overall acceptance, for example, unpleasant odours in the neighbourhood of the biogas plant, noise, traffic, threats to nature, and competition for agricultural and food production and security [11].

While the main objective is the reduction of both the rapid growth and amount of food waste and urban and municipal solid waste globally, present methods of waste management further burden and create more problems for the environment, making the production of biogas through the method of anaerobic digestion the most attractive alternate solution, which altogether contributes to the decarbonisation of the world [17]. Decarbonisation of society requires, among other things, intelligent waste management policies and the integration of technologies for reusing waste materials to the highest possible extent. The aim is to collect and process as much waste as potentially possible, which would be central to increasing the portion of renewable gases in the energy supply and thus reducing greenhouse gas emissions. One of the long-standing goals of the Paris Treaty [20] is to reduce the worldwide average high-temperature upsurge to 2 °C, to attain 1.5 °C, which would significantly lessen the impacts and risks of climate change. Overall, raw materials for biogas plants can be categorised into the following five sets:

**Animal waste**, comprising animal urine, manure, and wastewater from washing stables, are all model raw materials for anaerobic digestion. The quantity and quality of animal waste hinge on the category of animal, feed composition, and feeding methods. Also, it depends on its weight and physiological condition [9]. Nevertheless, animal manure has certain shortcomings; specifically, it typically comes in large quantities and therefore has low dry-matter content and yield, which might result in low biogas production per unit of processed raw material and high costs of raw material transportation. Furthermore, animal waste may contain antibiotics and heavy metals, which have adverse effects and outcomes on the process of anaerobic digestion and the reuse of digestate [9, 19].

**Garden and field wastes** represent another likely natural resource for biogas production, boasting a high dry matter portion, low transportation costs, low production of liquid digestate, and a high yield of biogas per unit of fresh weight. In contrast, long retention times are required for their digestion owing to their high levels of hemicellulose, cellulose, and lignin. Also, the carbon-to-nitrogen (C/N) proportion is high (typically above 50), which is hostile to the normal evolution of microorganisms and also increases the biogas plant and anaerobic digestion start-up delays [9]. Adding additives to waste has demonstrated an increase in the effectiveness of biostabilisation, which resulted in shorter times and reduced energy consumption to attain the same results; specifically, not less than 7.5% of additional digestate decreases the C/N ratio and therefore speeds up the process [18]. Remains in digestors are also challenging to get rid of when field and garden waste are processed [12, 13]. Within these types of waste, maize has the highest biogas yield, followed by rice and wheat [6].

**Industrial organic waste** typically consisting of beverage and food waste in addition to waste from starch, sugar, and fruit processing, is produced in enormous quantities. Waste with an extraordinary content of hydrocarbons, proteins, and fats is the most appropriate for biodigestion [2, 3].

**Municipal waste** is solid waste created in people's day-to-day lives and comprises garden waste, household waste, waste from cleaning, and commercial waste. Organic waste included fractions of household waste and comparable organic waste. Impurities such as metal, sand, plastic, and glass can have a significant impact on the process of a biogas plant and must be removed in advance [6-9].

**Food waste** comprises food waste from eateries, kitchenette waste from canteens and hotels, and waste from the processing of fruit, fat, vegetables, and flour, among others. In contrast with other categories of waste, food waste has a high content of salt and fat plus contaminations, for instance, bones, utensils, and additional kitchenware parts, which may harm pipes, pumps, and other utensils and must consequently be removed during the pretreatment phase [15, 16]. Municipal sludge includes numerous categories of produced and waste sludge from community wastewater treatment plants, which have a large volume, high water content, and are unstable. Sludge from secondary and primary sedimentation processes is rich in organic matter, the digestion of which is suitable and simple for anaerobic treatment and has comparable potential and features for biogas generation as animal manure.

## 2.1 *History of biogas production*

Perseverance and determination to lessen the use of petroleum reinvigorated the growth of new technological innovations for the employment of alternate energy sources for the manufacture of diverse blends such as innovative fuels. Biofuels were produced from available biogas for approximately 2050 to 3050 years for hygiene drives. Nevertheless, the principal recognised production of biogas originates from a cautiously planned system that began in England in 1895.

Interest in its use started during World War II, when Germany and France began to construct biogas production facilities and used this product to fuel tractors and vehicles. Afterward, awareness of biogas diminished then improved throughout the oil crisis of 1973 to 1974 with enhanced technological innovation in biogas production. Currently, Germany remains undoubtedly the world frontrunner in biogas generation and development [21].

## 2.2 *Concept of biogas*

Biogas is realised and produced when biological matter biodegrades in anaerobic situations (specifically, in the absence of oxygen [$O_2$]). This procedure yields a combination of gases, primarily $CO_2$ and methane, with minor amounts of other gases, such as hydrogen sulphide ($H_2S$). When the biogas is sieved to eliminate the $H_2S$, the resultant combination is burned and can be used as an energy and power source for lighting, cooking, and water heaters [22]. When dense, it is used as petroleum for automobiles. Biogas is used commercially and in large quantities to be nurtured and refined into the gas pipe and grid to generate electricity. The categories of organic substances used to create biogas comprise animal manure, food waste, and agricultural derivatives. Certain commercial arrangements used sewage to capture and produce biogas [23]. The principal advantage of biogas is that it is sustainable and renewable. Although the manufacture of oil and gas and additional fossil fuels might ultimately decline and rise, we will continuously be capable of producing biogas on the condition that the sun is shining and the plants are growing. Biogas has no conservatory and greenhouse emissions since the $CO_2$ that is discharged and allowed into the air when it is used or burned is not greater than what was being generated from the source when the organic matter was initially developed [24].

As previously observed, biological matter biodegrades under the influence of anaerobic situations, where methane is generated. From studies, it has been projected that, yearly, between 600 and 850 million metric tonnes of methane are generated and emitted into the air. Methane is a distant and far more powerful greenhouse gas than $CO_2$. Nevertheless, in a biogas structure, methane that is generated is eventually converted into $CO_2$ when the fuel is scorched. Eventually, the $CO_2$ produced is going to wind up in the atmosphere from natural degradation [25]. The biological substance used and recycled in biogas digesters is usually a waste product. Using biogas decreased the amounts of organic materials and additional household waste, such as food waste, that people sent to landfills. Also, biogas schemes create nutrient-rich sludge that can be diluted and converted into fertiliser for farms and greeneries. In this submission, biogas productions help to grow and expand energy independence, save money, and develop resilience [26].

Studies have shown that compressed natural gas acquired from biogas decreases greenhouse gas emissions by up to 92% compared to petroleum, along with other climate benefits. Anaerobic ingestion can reduce costs related to waste remediation and help local economies [22]. Prospective biogas schemes in the country could supplement more than 350,000 temporary construction works and 25,000 permanent works. Anaerobic ingestion also lessens odours and the danger of water and air contamination from livestock wastes. The digestate, which is the material residual after the digestion procedure, could be sold and used as fertiliser and manure in farms, thereby decreasing the requirement for chemical stimulants such as fertilizers. Also, it offers extra income when requested by farmers and sold as soil amendments and livestock bedding [27].

## 2.3 *Production of biogas*

The production of biogas occurs through a collection or nonstop procedure in one, two, or three multiphase stages. It uses largely biological matter from waste materials as the organic substrate. Biogas is classified as a carbon-neutral biofuel because it utilises $CO_2$ that was taken up in a photosynthetic process, gulped by vegetation from the atmosphere, and returned through waste fermentation. Biofuel safeguards the atmosphere from the effects of pathogens by decreasing the wastes that could decay in the exposed air, which could have augmented the chances of enticing disease-carrying and transmitting vectors [28].

Furthermore, biogas significantly lessens water and air contamination, aids in the preservation of greenery, open space, and forests, and substitutes inorganic manure and fertiliser with its digested remains. According to the EU, biogas products will produce 30% of clean energy and power sources. It is used to generate electricity, vehicle fuel, and heat, therefore replacing conservative sources of energy and power that create greenhouse gas emissions. Lately, biogas manufacturing has risen substantially. This is demonstrated by the rapid construction and development of biogas plants, which have been built entirely in Europe, Asia, and America, leaving Africa behind. In 2016, the world produced 20.1 kilo-tonne oil equivalent (ktoe) per year (this is equivalent to millions of tonnes of oil per year), with Europe producing 62% (12.5 ktoe per year). In 2014, EU fabrication increased to 14.2 ktoe per year, a 30.7% increase, and it is anticipated to reach 35.0 ktoe per year by 2025. Many European countries are exposed to and have faced numerous problems connected to the excessive organic and biological waste products from agriculture, industry, neighbourhoods, and households. Biogas production has been shown in studies to improve waste reduction by removing the accumulation of persistent and harmful trash while simultaneously lowering waste disposal costs [14].

## 2.4 *Categories of substrates*

Agriculture residues, animal dung, and diverse biological wastes from food (animal and vegetable sources), organic portions of household and public waste and sewage sludge, catering, and byproducts from harvests devoted to energy (including biofuels), such as sorghum and sugar cane, are commonly used for biogas production. These are categorised into numerous criteria: organic content, its source, dry matter content, and methane yield. These substrates typically have an extraordinarily high content of starch, sugar, fats, and proteins, which decay through anaerobic digestion [5].

## 2.5 *Challenges of biogas production*

Despite the many benefits of using biogas digesters, there remain issues and challenges that must be addressed to maximise and enhance fuel production and fabrication. Microorganisms that generate methane have particular requirements, for instance pH and temperature, which must be preserved within particular parameters for optimum production, which enhances and maximises the production rate and cost of biogas [29]. Additional issues and challenges are hydraulic retention time (HRT), which is defined as the standard time that the inputted organic substrate uses in the digester before the chemical reaction is complete and it is removed. By tropical temperature measurement, the HRT is 32 to 52 days, even though in colder areas such as China, France, the United States, and the United Kingdom, it may be up to 90 days whereby heating is not considered, which necessitates a larger digester capacity and increases costs. While digesters can save energy for small-scale and limited production in houses, defining the correct and precise economic equilibrium for large-scale and comprehensive production remains a separate issue and challenge [14].

## 2.6 *Domestic materials for biogas production*

Domestic materials used for biogas production include organic material found in the home, agriculture waste, domestic livestock residues, community solid waste, and industrial waste from food derivatives. The collection of biomass materials hinges on economic value, cutting emissions, boosting environmental energy requirements, and challenging energy poverty and sustainability [30]. The total energy generated from biogas is considerably greater than from liquid biofuels. Several other raw materials are likely to be utilised for biogas production, which comprises protein, carbohydrates, fats, cellulose, and hemicellulose. Domestic materials used in biogas production include food waste, agricultural waste, industrial waste, and biowaste found in municipal waste. The breakdown of manure with diverse substrates yields higher energy output and biogas production. This might result in making biogas plants increase economic value by supporting economic recovery and job creation, decreasing people's helplessness towards energy prices, reducing greenhouse gases, and improving fertiliser value [27].

Energy crops, agricultural waste, and manure were typically used for biogas production via anaerobic fermentation in European countries such as France, Australia, and Germany. These raw materials are proficient in energy production by nearly 75%. Additional ways and modes of biogas creation and sources in Europe include sewage sludge treatment plants and landfill gas recovery (18%), and other sources (10%) until 2015. Formerly, European nations made substantial development towards utilising industrial, municipal waste, and energy crops for biogas production. In Germany, for instance, the use of lawns, silage, and maize, besides the additional energy produced for biogas production, is increasing because of the considerably greater biogas yield and government encouragement and support. Biogas production is an advanced and mature technology frequently operated at housing-scale reactors using domestic waste and human waste residues [26].

Enormous numbers of organic wastes from plants, humans, and animals have been studied for the production of biogas and are well documented in the literature. A variety of plant materials comprise crops, for example, sugar cane, cassava, and corn, among others, and agricultural residues, for instance, cassava rhizomes, rice straw, corn cobs, wood, and wood residues (pulp wastes, sawdust, and paper mill waste). Others, for example, include molasses and bagasse from waste streams and sugar refineries, as well as rice husks from rice mills and palm oil extraction. Community and neighbourhood solid wastes can also be utilised as feedstock [24].

The old concept of waste-to-energy transformation is becoming more widely accepted because it can be cost-effective in converting once-to-be-disposed organic waste material into an advantage by generating electricity and biogas that is sold to the grid and utilised to generate operational electricity in the street, in communities, on-site, and usable heat in the household. Furthermore, it can result in reduced residual disposal costs and reduced waste volumes (WVs), and even other direct financial benefits by providing profitable credits for greenhouse gas reduction [23]. Smaller sewage treatment plants are obvious opportunities, in addition to any generator of organic waste from farms, meat and vegetable production, breweries, canning processors, waste cooking oils, cheese producers, and many more. Waste mixtures frequently enhance and improve gas production per entity. The benefits and advantages of biogas production are worth considering for any such waste processor or waste producer whose waste is not toxic or poisonous to anaerobes [31].

## 3. Research method

This study evaluates and illustrates the convergence of the utilisation and production of biogas towards housing development. The study examined the scientific processes of biogas production and utilisation in housing development jointly as a composite system. This study undertakes biogas production research on liquid household organic manure to develop alternatives and options for increasing biogas yield, to undertake biogas-production research for energy utilisation in housing, and to evaluate the results (quantity, energy content, and composition, among others) of the biogas-producing experiments.

The study takes on one household member in a residential area in Ibadan as a case study, and consequently, the amount of liquid humanoid manure generated is 438 $m^3$/year. Human fluid manure is insufficient on its own to produce the necessary biogas measure and fuel quality and quantity for the household's energy demand and supply requirements and needs, so it is necessary to use a variety of human wastes and byproducts, and it is necessary to incorporate a biomass plant into the household design. Meanwhile, biogas plants are in constant operation, and it is mandatory to provide the yield-enhancing biological matter in the yearly production cycle. This study applies human wastes and byproducts as biological additives in the production of the experimental variants. In the household, the disposal methods for biological wastes served as a significant part of selection besides enhancing methane yield (biogas yield). Table 1 shows a sample of the yearly amount of human organic additives and liquid manure for generating the experimental variants.

**Table 1.** The yearly quantity of human organic additives and liquid manure

| Sample of biological wastes for biogas production | Average quantity of organic wastes ($m^3$/year) | Average quantity of developed methane ($m^3$/day) |
|---|---|---|
| Liquid human manure | 438 | Σ 1.56* |
| Maize marc | 42.8 | |
| Fruit marc | 21.8 | |
| Corn silage | 24.5 | |

* 2.4 to 2.6 $m^3$ biogas

The conversion factors, according to the International Renewable Energy Agency (IRENA) [32], indicated that 1 $m^3$ of biogas is equivalent to 0.65 $m^3$ of methane, and 1 $m^3$ of methane is equivalent to 34 MJ of energy, while 1 $m^3$ of biogas is equal to 22 MJ of energy, and 1 $m^3$/day of biogas is equal to 8,060 MJ/year.

Based on the result in Table 1, 1.56 $m^3$ of methane was generated each day. 20 hours of process time, 88% constant engine loading, and 1.56 $m^3$ methane (2.4 to 2.6 $m^3$ biogas per day) are desirable every day. It has produced 52.8 MJ of energy and 0.6 kW of electrical power, bearing in mind that the efficacy of the machine entities is 92%. The heat and electric energy generated could be used for individual and household needs.

The biological wastes in Table 1 were generated in the household, and thus the required slurry needed in processing the system was provided by human waste, maize marc, fruit marc, and corn silage, which were put in the storage tank. Table 1 shows the options from which biogas can hypothetically be generated in a quality and quantity suitable for energy production. Depending on the result generated above, it is assumed that all biological matter is biodegraded in the biogas digester. Nevertheless, because of the characteristics of biogas built up, which is used for energy production, only biological matter that biodegrades quickly and is readily obtainable in adequate quantity and quality in the community and household is used. The used organic matter provided positive conditions for biogas production, and concurrently, biogas production facilitated waste disposal. As flavours and additives, corn silage, fruit marc, and maize marc have improved the quality of methane production, which is linked to consistent gas production and composition. The biogas production of these alternatives satisfies the settings of the application so that the engines can function accurately.

Various types of digesters exist; these include floating drum plants, balloon or bag digesters, and fixed dome plants. The study used a fixed dome plant with a length of 2,000 mm, a width of 1,500 mm and a depth of 2,000 mm. This is illustrated in Figure 1. The data was collected from these small-scale household biogas plants, which produced biogas in a constant process whereby the feedstock is incorporated and the biogas is removed and used every day. The main part is the digester plant, which is an airtight vessel in which bacteria breakdown biological waste through the practise of anaerobic fermentation, which generates biogas that is generally $CO_2$ and methane. The feedstock used and included in the digester comprises animal, food, and agricultural waste. The materials that are challenging for the bacteria to digest are avoided. The digester in this fixed dome plant comprises an underground septic tank made of concrete with a pipe that serves as an inlet. This is used for adding feedstock to the digester. The gas is generated under high pressure and is retained beneath the dome at the uppermost part of the digester. The biogas produced is collected and drained off from the digester through a pipe attached to the upper part of the dome. Just as biogas is created, the slurry is forced out of the digester through the outlet pipe into a collecting tank. This design contains a gas storage tank connected to the gas vent pipe. The facility has monitoring apparatuses to measure production more accurately and easily. Most of the tanks are calibrated in metre cubes ($m^3$). After collection, this biogas is used for lighting, heating, cooking, and generating electricity.

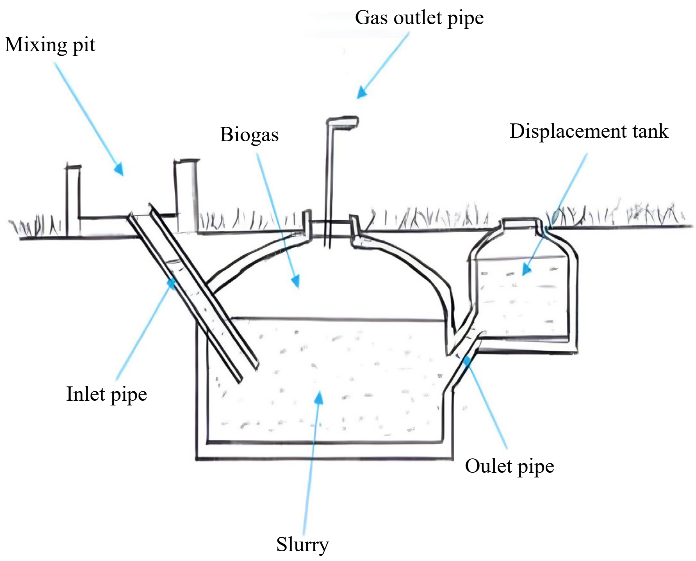


**Figure 1.** A typical fixed dome plant [32]

## 3.1 *The process and production of biogas for household use in the study*

The study used a suitable digester and an appropriate scale for domestic use. To initiate the system, the biomass is mixed with the right quantity of water in the mixing tank. The wastes, together with water, were mixed to generate the appropriate background environment for the bacteria to decompose the manure. This is an anaerobic process that occurred in an impermeable and airtight tank without the presence of $O_2$. This created the slurry. The slurry formed is transferred into the digester through the inlet chamber. After the digester has been moderately filled with slurry, the process of filling slurry into the digester is stopped, and the digester plant is kept and left unused for two months. After two months, the anaerobic bacteria present in the slurry fermented and decomposed the biological materials with the right mixture of water. With this outcome from anaerobic fermentation, biogas is generated, which starts to form and is collected in the dome area of the digester. The study used a starter biomass slurry of 9 to 12% of the total tank volume, which is sent into the digestion chamber. It takes 20 to 40 days for the system to digest slurry and start generating gas. Immediately after the digester starts its operation and process of biogas production, it produces 2.4 $m^3$ of biogas daily. Additionally, the digester provides 40 litres of agricultural fertiliser per day, which aids and enhances agriculture development. The biogas accumulated at the upper part of the tank was collected and transferred by pipe to the storage tank for domestic use. The slurry is removed regularly from the digester tank.

Just as the biogas is collected and stored in the storage, the pressure and forces generated and exerted by the biogas force the consumed slurry into the exit pipe to the outlet chamber. From the outlet chamber, the consumed slurry moves into the overspill tank. The consumed slurry is manually and physically removed from the overspill tank and is used as fertiliser for plant life. The gas stopcock linked to the pipes is unlocked when there is a need for a biogas supply. To have an uninterrupted delivery of biogas, an effective plant is loaded continuously with the prepared organic matter as slurry. It should be noted that committing to and relying on a single substrate limits and reduces the collective and overall importance of acquiring and having a digester in the homestead that is prepared to devour virtually anything. This study considered all organic inputs, including molded and rotten foods, to have a digester whose potential is unlimited. Food waste is frequently used because of its high energy potential, even though it has not been eaten or digested by the digestive system of an animal, especially foods with high sugar, calories, and starch. Other appropriate manures comprise cow, horse, sheep, rabbit, poultry, swine, goat, and others. It should be noted that once the gas is produced, manure is no longer required to keep the scheme going. Fruits, vegetables, dairy products, kitchen waste, meat scraps, fats, eggshells, and seeds are acceptable feedstocks at this moment; nevertheless, manure can remain as a fragment of the conditions if it's accessible.

The 7.2-$m^3$ digester system adopted can receive up to 0.6 $m^3$ of garden and food waste a day or 1.2 $m^3$ of manure slurry, including cat and dog waste. Every waste input is free of straw, soil, and nondigestible constituents, for instance, twigs and stones. Other suitable materials that were accepted and considered occasionally include citrus, cooking grease and oil, poultry manure, spinach, and fish. The constituents that were evaded comprised tissue paper, cardboard, feathers and fur, coffee grounds, wood chips, and sawdust. The images below provide a visual representation of biogas production and how it works.

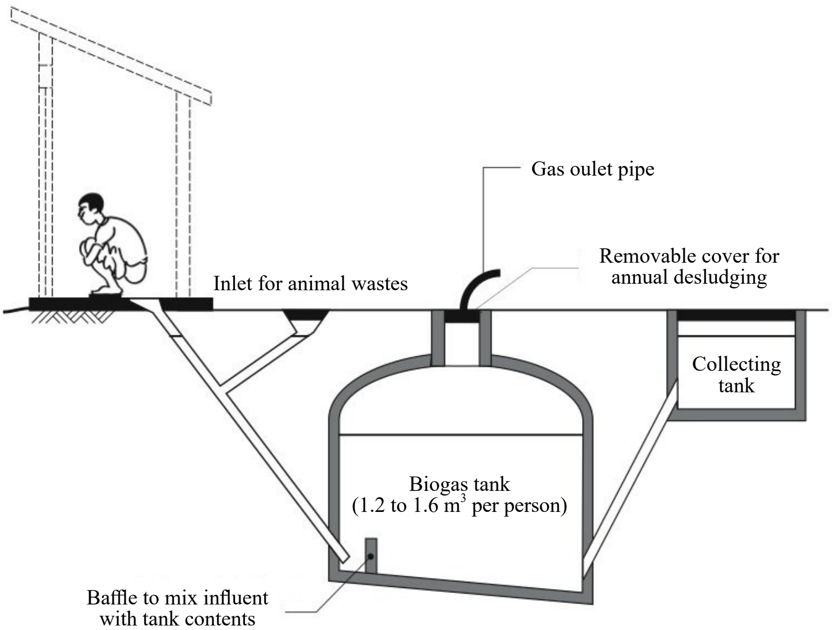


**Figure 2.** The typical illustrative model of an energy chain for biogas production

Figure 2 shows the typical illustrative model of an energy chain adapted to a biogas utilising and producing system. Other areas of a biogas scheme comprise a feeder pipe, from which waste materials from the kitchen, toilet, and other sources go into the digester. We also have an overflow tank or pipe that makes sure that the pressure and forces inside the digester remain constant and within safe confines. The other remarkable area of a biogas plant is the collection or outlet pipe for the liquid and solid residue, which is residual after the digestion course.

## 4. Results and discussion

The estimated daily gas production in this experimental study is 2.4 $m^3$, which is the volume of gas that the biogas plant is intended and designed to produce each day if operated under optimal conditions. The digester volume is 6 $m^3$. The multiplier suggests that the total plant volume would be 7.2 $m^3$. Three is the constant factor between the daily gas production and the total plant volume. The overall feedstock volume is the average or total amount of material added to the biogas plant every day. This is estimated to be 1.2 $m^3$. This comprises the amount of waste and other feedstock added daily (WV) and the volume of water added to these input raw materials (added water volume). The total feedstock volume (TFV) is documented in $m^3$/day; it is measured and recorded in litres and later converted to cubic meters. The WV is the measurement in $m^3$ of the biological material added to the digester. This comprises human, animal, agricultural, and food waste, in addition to other feedstocks used and collected in the digester. Water and waste are mixed before being added to the digester. This is for optimum biogas production; the ratio of the added water volume is equal to the WV in a ratio of 1:1.

For each category of material added to the biogas digester, the quantity of biogas generated depended on the quantity of the material converted and digested into biogas by the microorganisms in the digester. The quantity of feedstock (material) that is processed hinges on two factors: the volatile solid content and the total solid content of the material released into the digester. The volatile solid content is described as the amount of the solid materials that are processed and digested by the microorganisms and converted into biogas inside the digester. The total solid content of organic materials is the aggregate of the dry substances present in a significant amount of material. This is calculated as the load of the dry matter divided by the total load of the materials and documented as a percentage of the total load. So, for instance, if 1 kg of household kitchen and toilet waste encompasses 400 g of water, then its water content is 40% and the total solid content is 60%.

The average RT is the average total time that materials remained in the digester before they were forced out through the outlet pipe. The RT is measured in days and is simply calculated as the volume of the digester divided by the total volume of feedstock (the sum of the added water volume and daily waste). Since the digester volume is generally measured and calculated in $m^3$, for this reason, the feedstock volume is documented and recorded in $m^3$. For this study, 6 $m^3$ is the digester volume, while the TFV is 1.2 $m^3$. This means that the RT is 5 days. The temperature inside the digester is a significant factor that influences the speed, rate of gas production, and total quantity of biogas that is generated from any organic materials. In small-scale and homestead biogas plants such as those in this study, the microorganisms that form biogas work and digest most efficiently once the temperature of the slurry is 18 to 43 °C. Inside this temperature range, biogas generation differs; consequently, the magnitude of a biogas plant is made and designed to guarantee that day-to-day gas production is exploited.

**The storage of biogas:** The storage part acts as a tank, permitting downstream tools to function at a constant pressure. Biogas storage vessels have been constructed from a variety of materials. Medium- and high-pressure storage vessels were constructed of mild steel, while low-pressure storage vessels are made of steel, plastic, and concrete.

**The use of biogas for cooking:** A gas pipeline is connected to the uppermost part of the digester to transport the generated gas into the house (customarily the kitchen), where it is used as gas for cooking and heating. A hose is required to convey biogas from the digester into the cooking area. Cooktops for this structure comprise a regulator to control the biogas with a precise quantity of $O_2$, a burner to combust and flame the mix, and a configuration to grip the pot. Ovens and stoves for biogas use are comparable to those for conventional use running on commercial gas fuels. Many of these conventional and regular appliances are adapted for the use of biogas by extraordinary procedures (mainly the adjustment of the burners) to safeguard appropriate combustion and effective usage of energy.

**Conversion of biogas to electricity:** Apart from lighting, cooking, and heating water, it is possible to power a static generator that would typically work with gasoline or biogas fuel on the condition that it is filtered properly and cleaned after fuel structure alterations are completed. In theory, biogas is converted into electricity using a fuel cell. Nevertheless, this technique requires costly fuel cells and clean gas. Consequently, this option remains an issue in research and is not currently applicable. Meanwhile, the conversion of biogas to electronic power by a generator machine is very practical. Generally, biogas is used as a substitute for gasoline in engines that convert it into mechanical energy, which then powers an electric generator to produce electricity.

**Feasibility of biogas production:** Biogas development rests on the accessibility of water and space for the digester and the availability of feedstock. This is because biogas cannot be moved and transported over elongated distances; the structure has to be positioned very close to the household of its user, which needs adequate space. Hitherto, moving from a three-stone primitive method of fire generation to using a biogas cooker has required multifaceted modifications for a rural household area, in addition to the user. To check the feasibility of biogas, certain rudimentary points are useful to consider; one of them is the complex fermentation and biodegradation process in the biogas plant, which requires a nonstop supply of appropriate feedstock (if possible, domestic manure or other agricultural waste). This necessitates a suitable husbandry system in which an adequate quantity of livestock is kept and confined (no unconfined grazing). It necessitates a nonstop supply of water throughout the year, which is a constraint in arid regions or zones with a severe dry season. Households must be able to pay for the construction and development of a digester with a good stove. The economic feasibility improves when the slurry produced from the digester can be used as fertiliser on nearby agricultural fields. There must be enough labour available for the daily maintenance and feeding of the digester. Biogas construction is not advisable in cultures where preventive and maintenance action is not a regular habit. The rule of thumb recommends that four to five cows are required to make biogas production feasible at the household level. This rule of thumb may be problematic, particularly for a poorer household. Biogas inventions have an elongated and long life span. A household-scale biogas production plant in a house's backyard will last for up to 22 years and might need minor preventive and maintenance action throughout its lifespan.

**Integral errors in converting household waste to biogas:** Errors can occur during the process of converting household waste to biogas owing to inherent variations, a lack of information and knowledge, or deliberate selections regarding diverse technological decisions or ways. Errors due to uninformed choices that change the structure and configuration of the system, for instance, choices associated with certain treatment pathways or technologies, can be established by outlining qualitatively diverse situations and comparing the results of these situations alongside each other.

## 5. Built-form and fermentation processes

Figure 3 illustrates a system of underground reactors that could be adopted in place of the septic tank and soak-away systems of waste disposal currently used in many households. Figure 4 demonstrates the use of animal manure in biogas production. This could be adaptable in a farm settlement. Figure 5 shows a schematic overview of household waste for biogas production, while Figure 6 shows biogas production for cooking and lighting. Figure 7 illustrates the combination of household and agricultural products for biogas production. Figure 8 demonstrates a single-stage digester for biogas production in a residential building. Lastly, Figure 9 summarises the processes for the biogas production from household food waste and illustrates relevant implications for housing development.

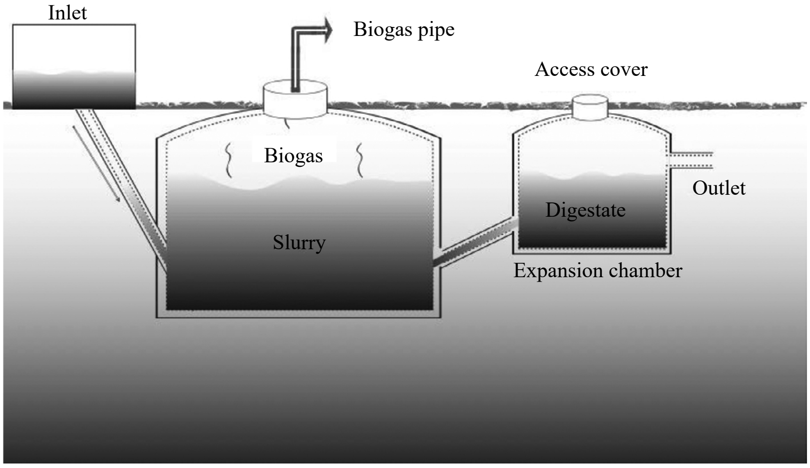


**Figure 3.** Underground reactor [14]

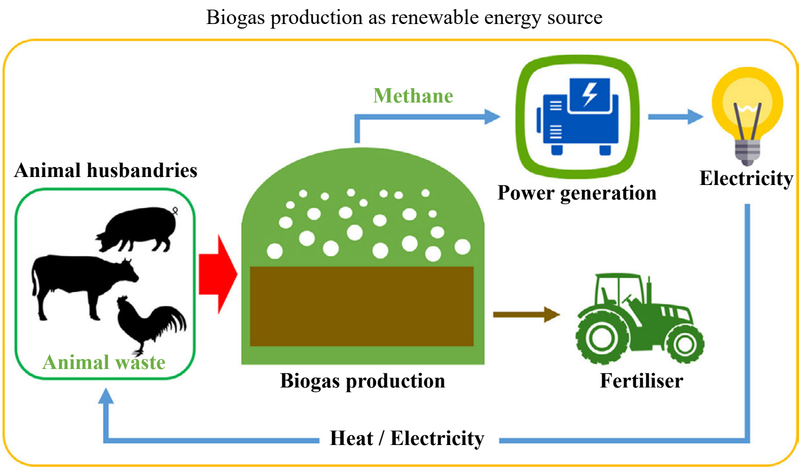


**Figure 4.** Animal manure usage in biogas production [33]

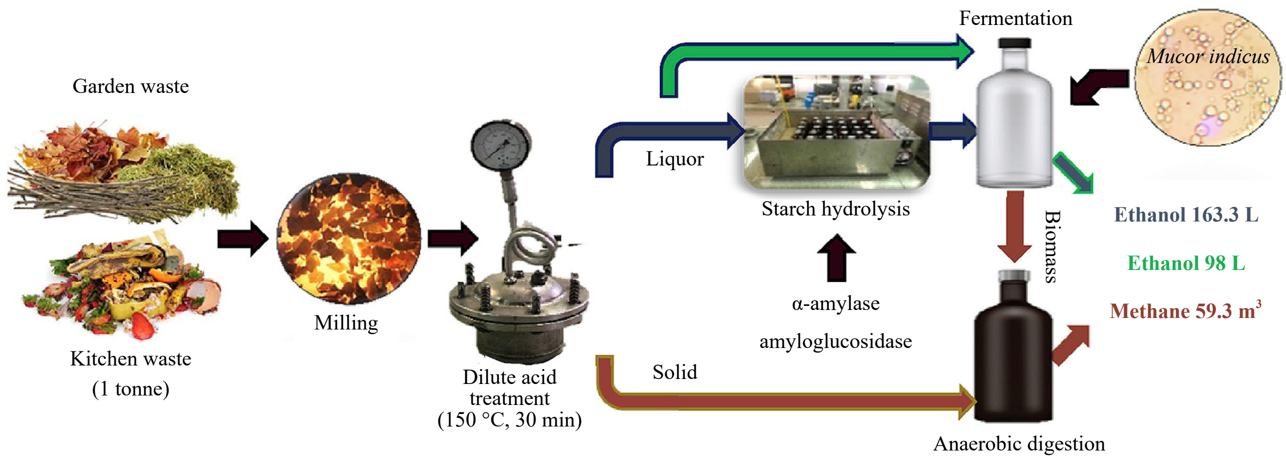


**Figure 5.** A schematic overview of household waste for biogas production [34]

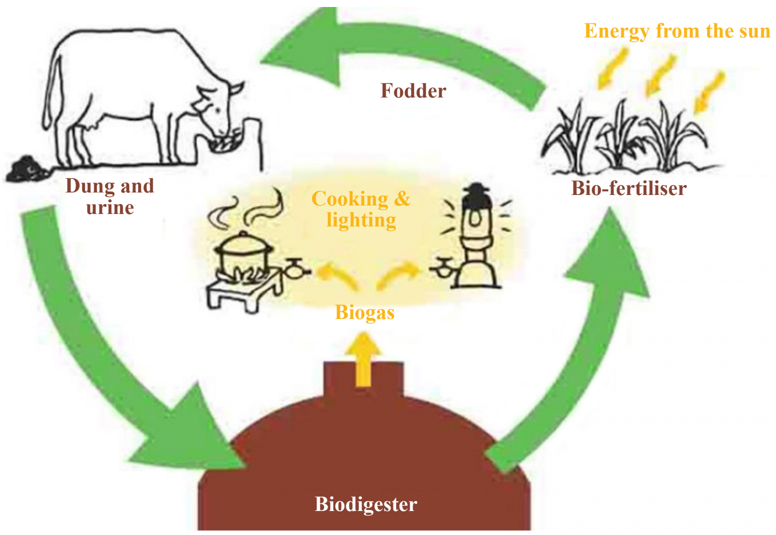


**Figure 6.** Biogas production for cooking and lighting [35]

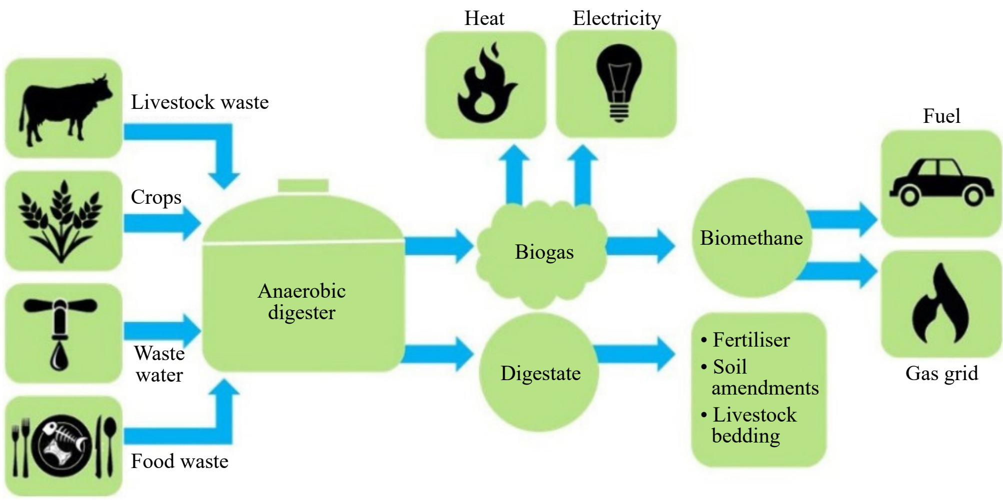


**Figure 7.** Combination of household agricultural products for biogas production [36]

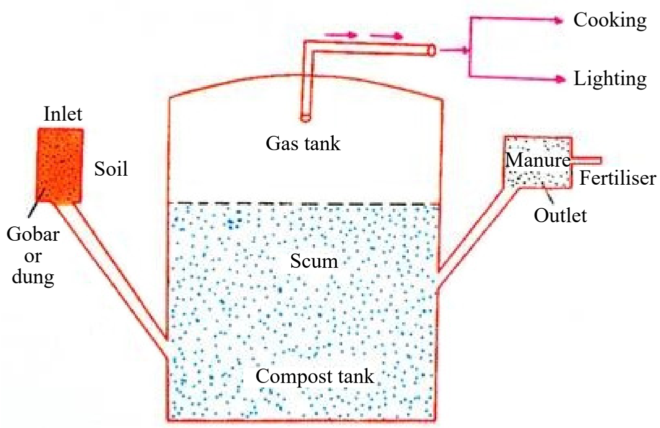


**Figure 8.** Single-stage digester for biogas production in homes [37]

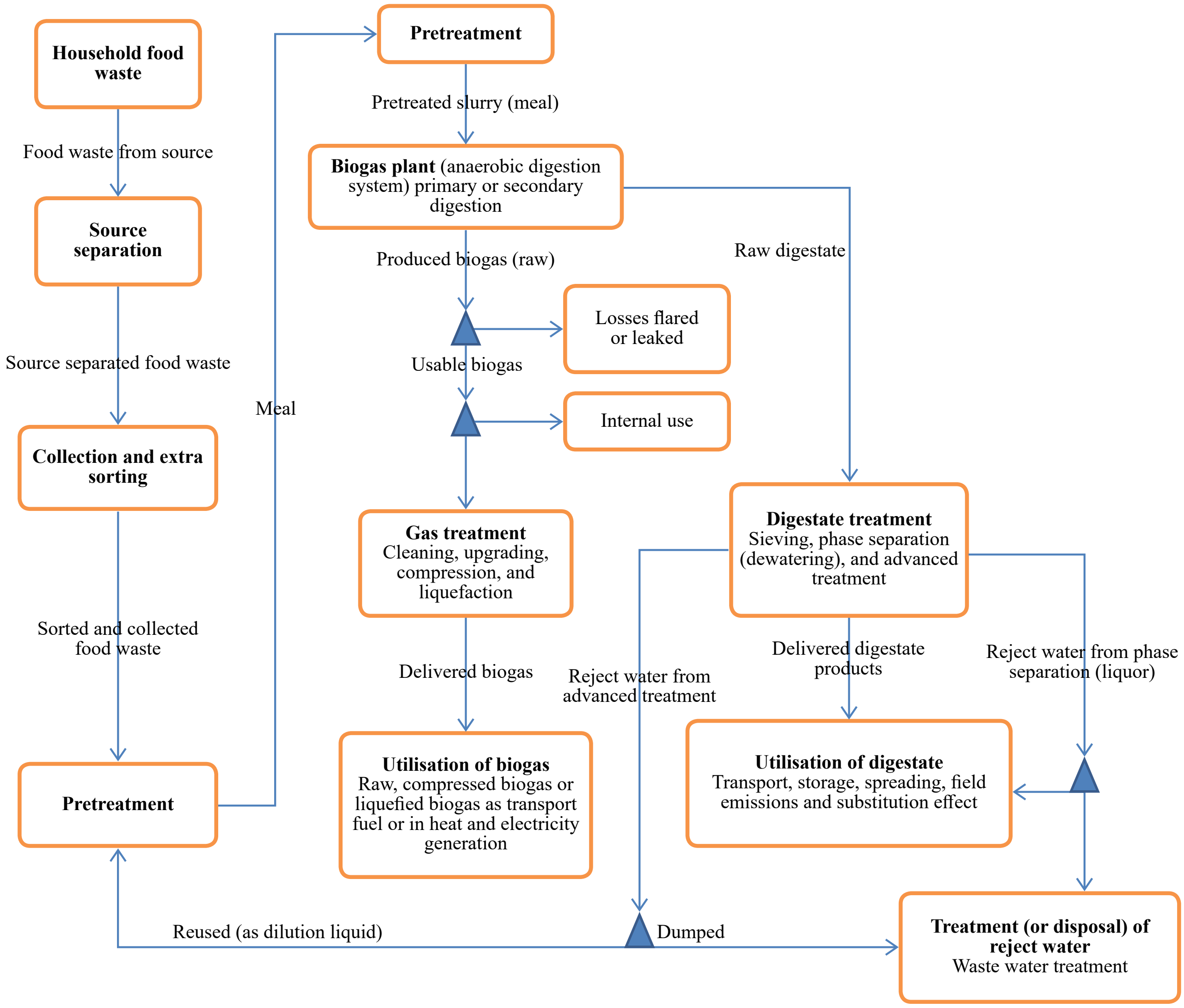


**Figure 9.** The processes for biogas production from household food waste and illustrations of relevant implications for housing development

## 6. Benchmark in biogas production

The benchmark is an important characteristic related to the performance, quality, and standard of the biogas production method and its utilisation in homes. This is used for in-depth analysis of a production method or comparisons between various production systems. To use biogas in the house, the quality of the biogas should be upgraded to match that of the natural gas used in a household. To attain the required standard and quality, contaminants that include $H_2S$, $CO_2$ and water vapour, among others, must be removed. Improved biogas is now ready to be used in the same way as natural gas. It has attained the quality standards of natural gas and is compressed up to the pressure required for household use. This study's quality and standard requirements defined the components of $O_2$, $H_2S$, and $CO_2$ particles that must be avoided and prevented from contaminating gas for household end-use and appliances. In summary, the production of biogas must comply with quality and standards through the implementation of benchmarks for biogas before injection into households. Table 2 illustrates the requirements for biogas before injection into households.

**Table 2.** Requirements for biogas before injection into households

| Elements | Unit | Requirement |
|---|---|---|
| $O_2$ | $m^3$ % | 0.6 |
| Water dew-point | °C | -11 |
| $H_2S$ | $mg/nm^3$ | 6 |
| $CO_2$ | Vol. % | < 9 |

To be utilised in homes, biogas production should meet some quality and standard requirements. For instance, to remove odours, the exact odours used in the natural gas scheme must be attained, and the pressure must be increased to equal the density and pressure in the respective section of the household. The cleansing process typically involves the separation and removal of $H_2S$, $O_2$, $CO_2$, and a minor amount of water vapour from the biogas, thereby reducing the wetness of the biogas. These consist of filters, separators, absorbers, and condensing apparatus. Separation of water from biogas is done using different methods that include cooling and absorption. The achievement of the quality biogas benchmark is the cleansing and purification process; when impurities are separated and removed, the methane content increases. To attain the mandatory standard of gas, these unwanted substances are removed.

## 7. Recommendations

For biogas production and usage to be a successful undertaking, there is a need for a market-oriented approach. Strict application of design standards and the quality of the digester structure should be followed. To monitor biogas consumption and production, it is essential to implement a comprehensive after-sales package that ensures reliable operational standards and the proper functioning of the plant; it is also essential to monitor the condition of biogas plants and the socioeconomic and environmental effects of biogas use on residents. The safety of the resident should be guaranteed. Open flames should be avoided, and never within seven metres of a biogas plant. Before any inspections or repairs, engineers should ensure that all the biogas generated is removed from the digester before moving in. The reason is that biogas will displace $O_2$ and cause choking and suffocation. The management of the system is significant. A digester must be fed with feedstock frequently to ensure a nonstop supply of gas. The supply and feeding of prepared slurry could take place on a weekly or daily basis.

It is necessary for professionals comprising of architects, urban planners, engineers, surveyors, and builders to incorporate the required spaces, facilities, and technology that can accommodate the conversion of waste to biogas in housing design and development. The septic tank should be redesigned from the conventional method to accommodate and embrace this new development. This did not necessitate any alteration or transformation of the current building structure or scheme. This scheme is an alternative to electricity and gas production for housing development. The training of experts from developed nations such as China, the United States, Germany, Japan, and other countries where utilisation of this technology is abounding should be tapped into and encouraged. Constant availability of raw materials is required in the biogas process and production, which comprise of: poultry wastes, animal dung, plant wastes, agricultural wastes, human excreta, industrial wastes (wastes from foodstuff processing activities), and domestic wastes (peels and vegetable waste). In a biogas plant, which produces flammable gas, the safety of the scheme is always vital. Maintenance is an occasional mechanism but a significant one. Any leakages in the digester pipe, liquid fittings, or tank must be resolved on time for performance and sanitary reasons.

Homegrown biogas production is uncommon. The governments should endeavour to draught rules to encourage its usage, and the indigenous government bodies should grant assistance and advice to house owners who are captivated by and show interest in its installation in their homes. This study supported waste-to-energy production in the hopes of achieving advancement in this field. The study demonstrated how home-based biogas is used successfully and safely. However, biogas is a flammable fuel, and one of the requirements is that it be free of toxic $H_2S$. Similar to any other energy source, biogas should be valued and used correctly. When compared to fossil gas, which is extremely hazardous, biogas should not be dreaded.

The technology for setting up home biogas systems is presently available in many developed countries, which we need to tap into. People who had been using it were overwhelmed by its simplicity, self-sufficiency, and functionality. In real-world situations, putting in approximately 4 kg of food waste daily will generate enough gas for cooking, occasionally twice a day. If, peradventure, you need additional gas, all you need to do is put in more organic matter that will generate decarbonised biogas and reduce household energy use. Each household will be separated from the conservative gas channel and such individuals will be richer and have extra money for other projects that will expand their comfort. With the disturbing levels of food waste in the country, converting this organic waste into sustainable and green energy is environmentally friendly.

Household biogas is extensively produced in developed countries around the world. The United Nations and World Bank are vigorously encouraging its usage as a safe, clean, cheap, and hygienic energy and power source for household use. China alone has 30 million biogas plants. However, developing countries such as Nigeria have been slow to exploit and utilise this enormous energy source potential. Provided that Nigeria, an African country, is among the world's most carbon-concentrated nations, which is not acceptable and very unfortunate. The inability to embrace and encourage home-based biogas is partially due to the nonexistence of strong guidelines about its usage and the Home-based Biogas Act. Virtually every Nigerian home has the potential to have an autonomous gas decanter to power its housing energy needs. Consequently, keeping gas in the household should not be a problem. According to studies, biogas systems' insulation usually came with robust insurance, warranties, and safety certificates, which would not normally include high-pressure gas pipes.

## 8. Conclusion

The study provides a comprehensive understanding of biogas production in housing and the design aspects, construction methods, operation systems, and maintenance issues of the biogas plants. This study provides an overview of the current situation in housing development in the field of waste processing into biogas, the suitability of waste on the path to decarbonisation, as well as national energy and climate plans related to waste-to-gas and the development of actual projects to reach these goals. The study observed that a small-scale biogas scheme for households typically consisted of the following components: collection space, raw materials, liquid slurry, solid and semi-solid animal waste, agricultural or human waste, slurry storage, and an anaerobic digester. Gas handling tools include piping, gas meter, gas pump or blower, condensate drain(s), and pressure regulator. Meanwhile, end-use devices include cookers, lighting, and boiler equipment. Digesters are produced in many sizes and forms, which range from 1 $m^3$ of biogas for small household units to some medium-sized 10 $m^3$ units for a typical and common farm plant and over 1,000 $m^3$ for a very large biogas installation.

This study has shown that a household in an optimal situation could be energy autonomous. The experimental variants, which generated biogas with less methane content, aided the ethics of sustainable development through the characteristics of biological waste disposal and management. Adoption of household organic waste conversion to biogas and use of biogas as an energy source will prevent the undesirable environmental effects that threaten and destroy our environment, thereby preventing environmental damage and harm. Small biogas production and utilisation systems can be manufactured in housing in such a way that both environmental and energy goals are met. The practical factors have delivered positive circumstances for the production and utilisation of biogas in homes. The presence of methane in the biogas satisfies the circumstances of utilisation. At the same time, waste disposal can also be accomplished. Even though biogas production is an ancient practise, little is known about its production and integration into Nigeria's housing development. Consequently, additional studies on the process and its production are required to attain better quality and, therefore, better outcomes for the process leading to production.

## Conflict of interest

The authors have no competing interests.

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