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Review Article

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Two alternatives to the current utilization of open municipal waste dumpsites by Edo State Waste Management Board (EMWB) in the management of solid waste streams in Benin city, Southern Nigeria

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A B S T R A C T

Municipal solid wastes evacuated from all private and commercial premises within Benin city are assembled at either of four (4) functional open dump sites located at several locations within the city and two (2) of these dump sites are being operated by the Edo State Waste Management Board (EMWB). Only Government accredited waste managers are allowed to utilize the open dumpsites. Human scavengers abound within the premises of these dumpsites and personnel at the respective dump sites periodically with the aid of a mechanical tipper moves and accumulate the wastes prior to open incineration. Aside from the negative impacts of these open dumpsites on the aesthetics of the affected environment, it is a crude and archaic process of wastes disposal which in the long run is unsustainable. A sanitary landfill has been described as a carefully engineered system designed to manage the effects of waste disposal on anthropogenic health, safety, and the environment. Biogas production using anaerobic digestion (AD) or bio-methanation is an environmentally friendly process that utilize increased quantities of organic waste components from agricultural, industrial and municipal waste sources as well as floral residues. Utilization of functional land fill sites and bio-gasification of solid waste streams are not novel phenomena and as such, the Edo State Government could adopt and utilize these options as viable alternatives to the currently utilized crude practice of disposal of municipal wastes in an open dump site.

INTRODUCTION

Sustainable development is often understood as progress that does not cause harm, emphasizing the careful and responsible use of non-renewable resources to benefit both current and future populations (Mensah, 2019). One of the most noticeable effects of rapid urban growth in Nigerian cities and towns is the increasing production of solid waste. Many municipal authorities struggle with numerous issues related to managing this waste, particularly when it comes to its collection and disposal (Ukala *et al.*, 2020). Although effective solid waste management is crucial for maintaining a healthy urban environment, the efforts of several municipal administrations in this area have generally fallen short of expectations (Ogu, 2000).

Benin city, which serves as the capital of Edo State, was already recognized as a prominent urban center in West Africa prior to Nigeria's establishment as a nation by the British in the late 1800s. Over the past sixty years, the city has undergone substantial expansion in both its area and population, making it one of Nigeria's leading cities today. For example, the population rose dramatically from approximately 53,700 in 1952 to more than 709,700 by 1991 (Ogu, 1996). According to Ogu (2000), Benin City's physical size also grew remarkably, with an increment from 949 ha in the year 1952 to 25,000 ha in the year 1991, a change largely driven by sub-urbanization, where nearby rural and peri-urban communities became part of the city.

At present, the Edo State Waste Management Board (EWMB), the official Government body in charge of managing municipal solid wastes (MSW) in Edo State, oversees two major open dumpsites situated in the outskirts of Benin City, specifically in the per-urban areas of Oluku and Ikueniro respectively (Okosun *et al*., 2023). There are also, two privately owned and operated open dumpsites located at the Upper St Saviour area of Benin city. Beyond the adverse effects these dumpsites have on the local environment and community standards, this method of waste disposal is outdated and primitive, making it an unsustainable solution over time.

OVERVIEW OF SOLID WASTE COLLECTION AND DISPOSAL BY EMWB

As of December 2015, the Edo State Waste Management Board (EMWB) had divided the developed areas of Benin City into approximately sixty-eight (68) zones for the purpose of waste collection and removal. These zones were assigned to various government-approved waste management operators. The waste managers were responsible for conducting a survey of both residential and commercial properties within their designated zones. During this survey, agreements regarding service terms were established between the potential clients and the waste managers. The waste managers gathered the necessary customer information and submitted it to the Edo State Ministry of Environment and Public Utilities, where the data was entered into a computerized billing system that generated invoices for the customers and the corresponding waste managers. The whole process is adequately summarized in Figure 1 below.

Figure 1: Waste management framework of the EWMB

Customers receive the designated State Government bank account name and number to make their payments, and they provide proof of payment to the waste managers, who then update their service records accordingly. However, some zones are directly serviced by the Edo State Waste Management Board (EMWB) itself. This arrangement serves as a practical example of a Public-Private Partnership. Waste collected from homes by both the government-approved waste managers and EMWB is typically transported to one of the two open dumpsites for disposal. Only waste managers accredited by the government are permitted to use the open dumpsites managed by EMWB. Within the dumpsite areas, informal scavengers are commonly found searching for recyclable materials such as plastic and glass bottles, ceramics, metal objects as well as cans, despite the unpleasant odors. Periodically, EMWB uses mechanical tippers to move and pile up the waste before conducting open burning. This process is essential to free up space, allowing trucks to navigate the dumpsites and deposit waste further inside, away from the entrance.

Problems associated with the usage of open dump sites

The open dumpsites operated by EMWB at Ikueniro and Oluku villages on the outskirts of Benin city have become a glaring eyesore. Residential buildings are situated very close to these sites, as the city has essentially expanded around these sites. Consequently, the regular controlled burning of waste at these dumps, although necessary to create space, has recently become a harmful practice, causing air pollution that affects nearby residents. The negative impact of waste accumulation and burning on the surrounding soil ecosystems is significant and difficult to quantify. Moreover, the continuous contamination of the soil where the waste is deposited has undoubtedly degraded the soil quality and may have also adversely affected the underlying groundwater aquifer.

SANITARY LAND FILL AS A VIABLE OPTION IN MUNICIPAL WASTE MANAGEMENT

A sanitary landfill has been described as a carefully engineered system designed to manage the effects of waste disposal on human health, safety, and the environment (Siddiqua *et al*., 2022). In contrast, an open dumpsite is considered an unregulated system that lacks any formal engineering design (Ajibade *et al*., 2021). Modern landfill definitions generally emphasize the principle of sequestering or isolating deposited waste from the environment until natural biological, chemical, and physical processes stabilize and neutralize the waste as much as possible (Ozbay *et al*., 2021). The primary distinctions among landfill definitions are related to the level of isolation provided and the methods used to achieve it. This isolation involves preventing water from infiltrating the landfill and controlling any direct emissions from the landfill into the surrounding environment (Adewole, 2009).

There are three fundamental types of practices and requirements for landfill management:

i) The consolidation and compaction of waste at the active landfill area to conserve space; designing and operating the landfill to manage settlement effectively s well as enhancing chemical and biological processes, such as landfill gas recovery, or both (Danthurebandara *et al*., 2012).

ii) The daily application of a cover layer over waste to minimize hazards associated with exposed refuse (Adewole, 2009).

iii) The control or prevention of negative environmental effects from land-disposed waste on soil, water, and air, as well as the protection of public health and safety from these impacts (Danthurebandara *et al*., 2012).

A properly functioning sanitary landfill must satisfy these three essential criteria irrespective of the economic status of the country where it is established (Adewole, 2009). Despite the technological and financial challenges in meeting these three conditions (Adewole, 2009), they can be achieved through dedicated collaboration between the Edo State Government and relevant private sector partners. In the short term, the priority should be to satisfy these conditions to the fullest extent possible under existing conditions (Adewole, 2009). The long-term objective must be full in compliance with all three essential requirements. A phased implementation is advised, as the benefits of a modern sanitary landfill are only fully realized when these basic standards are completely attained (Oyebode, 2017). Among these, the most critical condition is ensuring that the landfill does not harm public health or the environment (Vaverková, 2019).

Having a clear understanding of the volume as well as the physical and chemical composition of the waste to be deposited is essential for the effective design and management of a sanitary landfill (Adewole, 2009). These factors directly influence several aspects of the landfill's operation throughout its lifespan, and is also inclusive of paramters such as the annual fill rate, the total volume needed, the generation and nature of gases and leachate, as well as environmental consequences (Adewole, 2009).

BIOGAS BIOSYNTHESIS *VIA* ANAEROBIC DIGESTION (AD)

Anaerobic digestion (AD), also known as bio-methanation, has been described as the breakdown of organic substances by prokaryotes in an environment devoid of oxygen (Opejin, 2016). This process is known to entail four (4) key stages: hydrolysis, acidogenesis, acetogenesis and methanogenesis respectively (Aworanti *et al*., 2023). The end products of anaerobic digestion include: biogas and digestate, the latter of which can be utilized as a fertilizer (Harirchi *et al*., 2022). AD has been recognized as an efficient waste management method that supports sustainability principles throughout the entire supply chain (Alengebawy *et al*., 2024). Additionally, it can encourage industrial symbiosis, wherein waste from one industry becomes a valuable input for another (Harirchi *et al*., 2022).

Anaerobic digestion has been extensively adopted in Europe and is gaining traction in the United States, largely due to advancements in facility design (Huang, 2024; Marchior *et al*., 2025). The process is highly adaptable and can handle organic waste in varying volumes (Opejin, 2016). Nevertheless, the biggest challenge for AD, especially in developing countries, is achieving profitability (Adeleke *et al*., 2023). The monetary costs associated with installing and operating AD systems are often high relative to the immediate financial returns (Opejin, 2016). Several other factors also limit the full economic potential of AD, including the quantity and quality of feedstock, waste stream management and logistics, regulatory policies, and the market demand for its by-products such as energy and digestate (Oduor *et al*., 2022; Huang, 2024).

Anaerobic microorganisms, pretreatment, biomethanation and biogas production from wastes

As illustrated in Figure 2, Biogas forms naturally *via* the anaerobic decomposition of organic matter from plants or animals, and biogas formation usually takes place in settings like swamps, lake sediments, and landfills containing organic waste (Agbede *et al*., 2019). This gas comprises approximately of 55-65% methane (CH_4), 35-45% carbon (IV) oxide (CO_2), 0-1% hydrogen sulfide (H_2S), 0-1% nitrogen, 0-1% hydrogen, 0-3% carbon (II) oxide (CO), 0-2% oxygen, along with trace amounts of ammonia and water vapor (Kalia *et al*., 2000; Keefe, 2000).

Biogas is also known to have several attributes which include being clean, colourless, odourless and very flammable with a calorific content in the range of 4500–5000 kcal/m^3 (Igoni *et al*., 2008). Akpan *et al*. (2015) asserted that for biogas to be flammable, the methane content must be ≥ 40%. Biogas production occurs in anaerobic biodigesters, wherein bacteria and archaea are known to break down organic matter (Senés-Guerrero *et al*., 2019).

The quantity and makeup of biogas produced is dependent on the substrate type, microbial population involved as well as the specific conditions within the anaerobic digester (Agbede *et al*., 2019). Biogas can be directly utilized as a fuel for the purpose of heating, such as cooking, without needing to remove CO_2, or it can be directly converted into electricity (Manyi-Loh *et al*., 2013). Electricity generation from biogas requires internal combustion engines or turbines coupled to generators (Agbede *et al*., 2019). For vehicular fuel use, biogas can be upgraded to boost methane levels by eliminating CO_2, yielding 95-97% methane and 1-3% CO_2 (Dareioti *et al*., 2009). H_2S must also be extracted, since biogas in steam boilers or engines for power production cannot exceed 200 ppm H_2S (Agbede *et al*., 2019).

A diverse array of organic materials can serve as feedstock for anaerobic digestion. These feedstocks, known as substrates, encompass agricultural residues (such as leaves, roots, seeds, stalks, and seed shells), animal manure, energy crops, food waste, forestry crops and by-products, organic industrial waste and wastewater (like those from the food industry), weeds, aquatic algae, sewage, sludge, as well as the organic portion of municipal solid waste (Khan *et al*., 2017). The organic component of municipal solid waste (MSW) is known to encompass kitchen scraps (primarily leftover food), paper and cardboard, textiles, food remnants, as well as garden and wood wastes (Hartmann and Ahring, 2006; Jha *et al*., 2008). Among the most commonly used substrates for anaerobic digestion are animal manure and organic sludge produced from aerobic effluent treatment methods (Horváth *et al*., 2016). Anaerobic digestion is known to be capable of processing both dry and wet feedstocks: wet digestion typically uses a pump able slurry containing about 15% dry solids by weight, while dry feedstocks are solid enough to be stacked (Agbede *et al*., 2019).

Feedstocks derived from flora that harbor lignin, cellulose and hemicellulose are known as lignocellulosic feedstocks, while feedstocks without these components such as animal manure, are categorized as non-lignocellulosic (Capolupo and Faraco, 2016; Ojo, 2023). Materials used in anaerobic digestion can include energy-rich compounds like sugars, starches, and fats, as well as lignocellulosic substances, which are more challenging to break down (Manyi-Loh and

Lues, 2023). The specific makeup of the feedstock largely determines how readily it can be decomposed and its effectiveness for biogas generation (Agbede *et al*., 2019). Lignocellulosic feedstocks decompose at a slower rate during hydrolysis, requiring extended treatment periods and larger digester volumes compared to non-lignocellulosic materials, which are more easily broken down or dissolved (Amin *et al*., 2017). Excessive quantities of high-energy feedstocks, exemplified by fats, can disrupt the anaerobic digestion process, especially during the methanogenesis phase (Rehman *et al*., 2019). As lignocellulosic materials are difficult to digest anaerobically, they are usually subjected to pre-treatment to aid biogas synthesis and production (Zhang *et al*., 2016).

A variety of approaches such as chemical, physical, or biological approaches can be used in pre-treating substrates. Physical pre-treatment methods include mechanical actions like high-shear mixing, ball milling as well as grating with sandpaper or mesh (Lindner *et al*., 2015; Tsapekos *et al*., 2015), as well as applying heat or thermal disruption (Zhang *et al*., 2016). Anaerobic digestion feedstocks may consist of high-energy compounds like sugars, starches, and fats, as well as lignocellulosic materials, which are more resistant to breakdown (Manyi-Loh and Lues, 2023).

The composition of the feedstock is a key factor in determining how easily it decomposes and its potential for biogas production (Agbede *et al*., 2019). Lignocellulosic feedstocks are known to break down slowly during hydrolysis and as such, require longer processing periods and bigger reactor content for anaerobic digestion in comparison to non-lignocellulosic substrates, which are more easily hydrolyzed or dissolved (Amin *et al*., 2017). Using large quantities of high-energy substrates like fats can also interfere with the anaerobic digestion process, particularly the methanogenesis stage (Rehman *et al*., 2019).

As lignocellulosic materials are resistant to anaerobic breakdown, they are typically pre-treated to improve biogas yields (Zhang *et al*., 2016). Pretreatment of substrates can be accomplished through chemical, physical, or biological methods. Physical pre-treatment techniques include mechanical processes such as high-shear mixing, ball milling, and grating with sandpaper or mesh (Lindner *et al*., 2015; Tsapekos *et al*., 2015), as well as thermal disruption methods (Zhang *et al*., 2016).

The organic components of MSW have been individually transformed into biogas in bio-digesters *via* the process of biomethanation (Macias-Corral *et al*., 2008; Karagiannidis and Perkoulidis, 2009). Anaerobic co-digestion is a process wherein multiple types of feedstocks are digested together in a single digester (Agbede *et al*., 2019). This technique is often used to optimize the carbon-to-nitrogen (C/N) ratio of the materials being digested; for example, cattle manure can be processed together with flora-based biomass (Zhang *et al*., 2016). Some advantages associated with co-digestion include; the capacity to process a very wide range of substrates, improved microbial synergy, greater process stability, elevated biogas output, enhanced nutrient recycling as well as reduced odor production (Zhang *et al*., 2014). Biogas generation *via* anaerobic digestion is reliant on the combined activities of several microbial communities (Goswami *et al*., 2016).

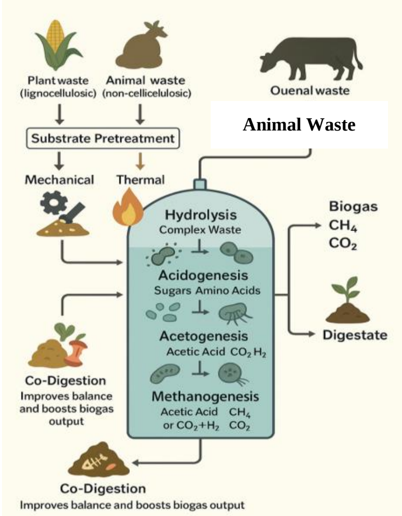

Figure 2: Process of AD for biogas production

According to Heeg *et al*. (2014), the process begins with bacteria (prokaryotes) that are primarily responsible for breaking down complex organic compounds through hydrolysis (Goswami *et al*., 2016). The resulting simple molecules and oligomers are then further broken down by other microbes to produce volatile fatty acids (VFAs) during acidogenesis, and subsequently converted into acetic acid, CO_2 as well as hydrogen during acetogenesis (Goswami *et al*., 2016). In the final stage, known as methanogenesis, specialized Archaea—either acetoclastic or hydrogenotrophic—convert acetic acid or a combination of carbon (IV) oxide and hydrogen into methane.

Biogas Generation in Nigeria and Constraints Affecting Biogas Production

It has been reported that if a vast majority of Nigerian households deliberately switch to using biogas for cooking instead of diesel, firewood, charcoal, or kerosene, it would greatly lower greenhouse gas (GHG) emissions (Oyedepo, 2012). Biogas is also safe for health, does not produce any unpleasant odors, and burns with a clean, blue, smokeless flame, which can keep kitchens and cooking utensils free from soot and mess (Shaaban and Petinrin, 2014). In Nigeria, cost-effective feedstocks for biogas production encompass animal manure, water hyacinth, cassava leaves, solid and industrial waste, water lettuce, urban refuse, agricultural residues, and sewage (Simonyan and Fasina, 2013). The country has also been documented to generate approximately 227,500 tonnes of fresh animal waste on a daily basis and about 20 kg of MSW per individual annually (Mshandete and Parawira, 2009). As 1 kg of fresh animal waste can potentially yield approximately 0.03 m^3 of biogas, Nigeria has the capacity and potential to generate an estimated 6.8 million m^3 of biogas on a daily basis (Shaaban and Petinrin, 2014). An increment in biogas generation and utilization can boost the country's energy supply and also offer an effective and profitable solution for managing—and potentially eliminating—the myriad of problems attributed to the improper management of MSW (Shaaban and Petinrin, 2014).

Although biogas technology is well-established and widely utilized in countries such as; China, Ireland, England, Germany, the Netherlands, the nordic countries (Sweden, Denmark and Norway), South Korea, Brazil and India, its development has remained limited in many African nations (Akinbomi *et al*., 2014). The rapid advancement of biogas technologies in numerous European nations has been driven by various strategies, notably the European Union's Renewable Energy Directive (RED), which set a mandatory objective for member states to achieve 20% renewable energy consumption by 2020 (Capodaglio *et al*., 2016). In Europe, the United States and Latin America, biogas systems are typically large-scale, with the generated biogas being utilized for multiple purposes including electricity production, district heating, injection into natural gas grids, and as fuel for different classes of vehicles and trains respectively (Akinbomi *et al*., 2014). Conversely, in many Asian and some African countries, biogas technologies is mostly implemented on a smaller, household level, wherein the generated biogas is primarily utilized for a variety of domestic activities exemplified by cooking (Sorda *et al*., 2010).

In Nigeria, several biogas initiatives have been carried out, exempified by the establishment of biogas production facilities at Zaria Prison in Kaduna State, North central Nigeria, Ojokoro in Lagos State, Western Nigeria, Mayflower School in Ikene, Ogun State, Western Nigeria and Usman Dan Fodiyo University in Sokoto State, Northwestern Nigeria with digester capacities varying from 10 to 20 m^3 respectively (Ilori *et al*., 2007; Ojolo *et al*., 2007; Igoni *et al*., 2008). However, these biogas ventures have yet to reach commercialization, as many are either non-functional or have remained in the research phase (Akinbomi *et al*., 2014).

The limited success of pilot biogas programs and the slow progress in biogas development and adoption in Nigeria has been linked to several challenges, including: (i) absence of clear policy frameworks, (ii) poor enforcement of existing biofuel policies, (iii) insufficient government commitment, (iv) technical shortcomings such as lack of spare parts and untrained personnel, (v) ineffective waste management systems, (vi) inadequate storage and transportation infrastructure, (vii) discontinuity of previous biogas initiatives by successive administrations, (viii) lack of proper structural facilities, and (ix) low public awareness of the benefits of biogas technology (Akinbomi *et al*., 2014).

The existing energy landscape in Nigeria has indicated that biogas has not been integrated into the country's energy mix, which is predominantly comprise of fuel-wood, petroleum products, hydroelectric power, and increasingly, solar energy (Chanchangi *et al*., 2023; Adeshina *et al*., 2024). An illustrative summary of the constraints affecting the production of biogas in Nigeria is presented in Figure 3.

Figure 3: Summary of challenges to biogas adoption in Nigeria

An example of an operational large-scale biogas facility in Edo State, Southern Nigeria is the one managed by Presco Agro Allied Farms at the Obaretin oil palm estate near Benin City, Edo State. This sizable anaerobic digester was commissioned and has been in continuous operation since April 2014 (SIAT Group, 2017). The plant is known to comprise of 2 x 9,500 m^3 capacity reactors and has an installed capacity of 160.000 m^3/ palm oil mill effluent (POME) per year with a potential yearly biogas production yield of 4.000.000m^3 biogas/year (1Nm^3 of methane gas is equivalent to 1 Lt of diesel) (SIAT Group, 2017). As at the end of the year 2017, SIAT Group, the parent company of Presco, had processed nearly 950,000 m^3 of palm oil mill effluent (POME), effectively removing about 56,500,000 kg of chemical oxygen demand (COD) organic load. Additionally, SIAT has repurposed some of the sludge and treated effluents as organic fertilizer for the plantation, which has helped reduce the use of chemical fertilizers in certain plantation areas where the anaerobic sludge is applied (SIAT Group, 2017). Presco Nigeria, under SIAT Group, plans to expand its electricity generation capacity to 4 megawatts using a biogas-powered generator set (SIAT Group, 2017). Currently, the oil palm estate operates independently of the national electrical grid, relying entirely on electricity produced from biogas generated by its anaerobic digestion plant, which also serves as a method for organic waste reduction and treatment.

Implementable recommendations for effective solid waste management in Edo state

To achieve reliable and efficient wastes management in Benin City, Edo State and other urban areas in the State and the country in general, the following steps should be taken:

Wastes sorting and source and at site

Public enlightenment campaigns and educational programs should be conducted to encourage households and institutions to sort waste at the point of generation. This practice, which includes separating food waste, plastics, metals, and textiles, simplifies recycling and biogas feedstock preparation. Implementing a color-coded bin system across neighborhoods will also help enforce sorting practices (Oluwafemi *et al*., 2021).

Organized system of waste recycling

The Edo State Government (ESG) should invest in organized recycling hubs within local government areas, backed by digital tracking of recyclable waste flows. This will improve collection efficiency, reduce informal scavenging risks, and create green jobs. Government monitoring and certification will ensure quality and safety in recycled materials handling (Ezeudu *et al*., 2021).

Establishment of functional AD plants

To overcome the lack of infrastructure, functional anaerobic digestion plants should be established in high-waste-density zones. These plants will convert biodegradable waste into biogas and digestate, addressing both energy needs and organic fertilizer demands. Training of local engineers and use of modular AD technologies are essential for sustainability (Adeleke *et al*., 2023).

The provision of an enabling environment for private sector involvement in biogas production

ESG can introduce tax incentives, low-interest loans, and subsidies to attract private investors to the biogas sector. Stable policies and streamlined licensing processes will further encourage participation. Public-private partnerships (PPPs) should be explored to bridge funding and technical gaps (Alabi *et al.*, 2020).

Maintain good sanitation laws and policy

Effective implementation of sanitation laws will reduce illegal dumping and open burning of solid wastes, as both of these practices are known to hinder effective and organized waste management. EWMB can in collaboration with relevant Local Government authorities ensure compliance of individuals and businesses *via* the payment of stipulated fines as well as ensuring the functioning of environmental sanitation courts (Ezeudu, 2020).

Building and maintaining standard landfills

Modern engineered landfills with leachate collection systems, gas recovery units, and perimeter fencing should replace existing dumpsites. These landfills must be sited using environmental impact assessments to avoid water and air contamination. Regular maintenance and operational transparency will boost public trust (Alao *et al.*, 2024).

CONCLUSION

Utilization of functional landfill sites for solid waste disposal and management by municipalities worldwide is well established, and the ESG can adopt and adapt the landfill approach as a better alternative to the current rudimentary open dumping method. It is both urgent and essential for the ESG to prioritize the implementation of more modernized and effective solid waste management strategies, including landfills and harnessing solid waste streams for biogas production, alongside other waste reduction methods such as recycling, composting, and reuse, especially given the current rapid suburban expansion within rural areas surrounding Benin City.

The Presco case has clearly demonstrated the effectiveness of biomethanation in meeting growing energy demands while reducing organic waste generated by human activities. Although bio-gasification is competing directly with other renewable energy sources like solar and wind, its ability to utilize MSW as feedstock offers a distinct advantage over these alternatives. This review has identified numerous challenges hindering efficient waste management in Benin City and proposed various solutions to overcome these issues, with specific reference to Benin city and Edo State in general. This report has revealed the various challenges militating against effective and efficient management of wastes particularly in Benin City. Various solutions to surmount this problem in wastes management in Africa with specific reference to Benin city, Edo State, have been propounded.

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