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WASTE TO ENERGY: REVIEW ON THE DEVELOPMENT OF LAND FILL GAS FOR POWER GENERATION IN SUB-SAHARAN AFRICA

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Abstract: This study focused on the development of land fill gas for power generation in Sub-Saharan Africa. In rapidly expanding cities in developing and emerging nations, it has been observed that municipal solid waste (MSW) has increased dramatically, raising public concern about the effects on the environment and public health. In Sub-Saharan Africa today, the garbage of people within this region especially in Nigeria is carelessly disposed. Environmental pollution and its effects on people's quality of life have become more sensitive topics among residents and decision-makers in Sub-Saharan Africa. Additionally, municipal solid waste management (MSWM) is becoming a more important topic on the local political agenda. Local decision-makers routinely debate whether to invest in waste-to-energy technologies as part of their effort to modernize waste management systems. Waste-to-Energy technologies are being promoted more and more as an alluring solution to a number of problems, including the urgent issue of waste disposal. These issues include inadequate power production, a shortage of landfill space, and greenhouse gas emissions from improper waste management. As an alternative to waste burning and composting, landfilling is one of the municipal solid waste (MSW) disposal techniques that are most frequently used. Due to its financial benefits, the sanitary landfill method is still often employed in various nations for the final disposal of solid waste. Landfill gas (LFG) is mostly produced by the anaerobic breakdown of the biodegradable component of municipal solid waste (MSW), specifically kitchen and yard trash, which is disposed of in landfills. Due to the anaerobic breakdown of the organic portion of solid waste, landfill gas is continuously produced. As a result, if an extraction system is not constructed in a landfill, there will be an overpressure that will force the biogas to be released into the atmosphere, which will have an adverse effect on the environment. Methane and carbon dioxide make up the majority of the gases that make up landfill gas, which is a mixture of other gases. Many landfill sites include an operational gas collection system that draws gas from both horizontal and vertical gas wells using a blower. The gas from the landfill was thought to only include carbon dioxide and methane. Methane's typical volume composition is 49%, hence it was believed that carbon dioxide would have a volume composition of 51%. Reviewing the information gathered by numerous studies regarding the volume of waste being dumped in landfills reveals that the waste produced in sub-Saharan Africa is sufficient to power the area with electricity. It was discovered that the quantity of electricity generated will fluctuate over time based on the flow rate of landfill gas. It will initially rise until a peak is attained. A million tons of landfill waste typically emits 434,000 cubic feet of LFG each day, which is sufficient to generate 0.80 MW of power. About 70% of LFG projects use internal combustion engines, gas turbines, and micro-turbines to produce power.

Keywords: Landfill gas, Power generation, Sub-Saharan Africa, Waste management, Waste-to-energy technologies

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1. Introduction

Geographically speaking, Sub-Saharan Africa is the portion of the African continent south of the Sahara (Ehsan et al., 2019). According to the United Nations definition, the term may also cover countries that only have a portion of their territory located in that region, in addition to the African countries and territories that are totally situated in that particular region (UN). The African Union's regional definition of sub-Saharan Africa includes the northern Sudan, but Mauritania is left out according to the UN geoscheme for Africa (Aguilar-Virgen et al., 2014). The inevitable outcome of population growth and urbanization causes an increasing rate of garbage creation across the board, including municipal solid waste (MSW), industrial waste, and packaging waste (Aronica et al., 2009). MSW is the term used to describe nonhazardous garbage produced in homes, markets, streets, and industries (Zuber and Ali, 2015). Landfill gas (LFG), whose primary components are typically methane (CH_4: 55–60% v/v) and carbon dioxide (CO_2: 40–45% v/v), is produced when biodegradable organic matter in landfilled MSW undergoes anaerobic breakdown (Trapani et al., 2013; Kumar and Sharma, 2014). Global warming is a result of the LFG being released into the atmosphere without being treated (Barbaro et al., 2009). Due to this circumstance, MSW landfilling is one of the most significant human-caused sources of greenhouse gas emissions (Aronica et al., 2009; Ishigaki et al., 2005; Trapani et al., 2013). Landfill gas (LFG) control methods are employed to stop the gas from spreading into the atmosphere unintentionally. The recovered Landfill gas (LFG) can be burned in flares under regulated conditions to prevent the release of dangerous components into the atmosphere or be utilized to generate energy (Scheutz et al., 2011). Landfilling's greenhouse gas emissions are reduced via energy recovery from LFG (Calabro, 2009). The advantages of energy recovery from LFG for the environment and the economy were reported by Johari et al. in 2012. As a result, sanitary landfills could serve as a source of renewable energy for sustainable development (Tsai, 2007). Compared to earlier times, technological advancements in LFG energy recovery have also helped to reduce greenhouse gas emissions (Weitz et al., 2002). According to Calabro et al. (2015), the European Union (EU) adopted a gradual transition strategy from municipal solid waste (MSW) management practices based on landfills to integrated waste management techniques, such as recycling, mechanical biological treatment (MBT), incineration with energy recovery, and landfilling. Greenhouse gas emissions have already decreased as a result of these practices (Christensen et al., 2015). Additionally, it was emphasized that increasing gas collection efficiency is crucial since it will have a direct impact on how much of an impact landfill gas (LFG) will have (Calabro et al., 2011; Niskanen et al., 2013). The ideal choice for landfilling has been suggested to be very restricted landfill disposal with high levels of gas collection efficiency for residual waste management (Calabro, 2009; Calabro et al., 2015). Landfilling continues to be the most popular technique of disposing of municipal solid waste (MSW) in developing nations like Turkey, despite its detrimental environmental effects (Salihoglu et al., 2018). The fact that landfilling is one of the most affordable methods of disposing of municipal solid waste (MSW) has led to its popularity (Kumar and Sharma, 2014). Energy recovery has received a lot of attention from researchers, energy corporations, and landfill operators due to the revenue gained by the energy produced by the utilization of the LFG (Scarlat et al., 2015). Increases in LFG-to-energy conversion practices are encouraged by government incentives like the feed-in tariff and renewable obligation certificates (Emkes et al., 2015). Although energy recovery costs and revenues differ between sites (Emkes et al., 2015), landfill operators are always working to increase the rate at which landfill gas (LFG) is generated and collected (Czepiel et al., 2003). Designing landfill gas-to-energy projects involves considering estimates of LFG recovery potential (Cossu and Muntoni, 1997). The final amount of gases produced from a landfill will depend on the amount of trash dumped, the garbage's properties, the technologies employed to handle and dispose of the waste, and the sort of surface-covering system used (Cossu and Muntoni 1997; Fecil et al., 2003; Friedrich and Trois, 2011). Additional factors include weather patterns and seasonal temperature variations (Czepiel et al., 2003; Barbaro et al., 2009). According to certain reports, the variables influencing the volume of gas vary between developing and developed nations (Friedrich and Trois, 2010). All waste categories, but particularly the organic component, have a wider diversity of material features in developing countries; claim Troschinetz and Mihelcic (2009) which is due to seasonal factors, affluence, domestic fuel supply, and geography. In many nations, models that are primarily based on the first-order decay of organic matter in municipal solid waste (MSW) are used to predict landfill gas emissions (LFG) (Ehsan et al., 2019). The results of these models may be highly unpredictable due to a lack of information regarding landfills and practices, waste composition, quantity of landfilled trash, or changes in management techniques (Scharff and Jacobs, 2006). Therefore, it is always required to have field measurements that indicate the properties of the waste, the working principles of the landfill, the MSW management plan of a particular town and the influence of the local climate (Bogner and Spokas, 1993). This study aims to assess the viability of using landfill gas (LFG) in Sub-Saharan Africa energy facilities. Investigated were the effects of the variables impacting landfill gas (LFG) production and, consequently, energy production. The field's extant literature has very little monitoring data from the practices of landfill gas (LFG) collection and energy conversion (Gollapalli and Kota, 2018). By analyzing real monitoring data from a major Turkish city, Bursa, this study seeks to add to the body of literature.

This study focused on waste to energy: Review on the development of land fill gas for power generation in Sub-Saharan Africa.

2. General Terms

2.1. Meaning Landfill

A landfill is a location for disposing of waste where the waste is often buried underground. One of the oldest and most popular ways to dispose of waste is to use a landfill, which separates trash from the surrounding region (Idehai et al., 2015).

2.2. Type of Gas Released in Landfills

Although a number of gases are emitted in landfills, methane, a damaging greenhouse gas, accounts for the majority (more than 50% of the overall volume). Man-made trash is the third largest producer of methane, which is around 21 times more potent than carbon dioxide and the main issue when it comes to landfill gas (Jaramillo et al., 2005). When garbage is dumped into a landfill, it initially goes through an aerobic (or "with oxygen") decomposition stage, which produces very little methane. Anaerobic conditions—or "without oxygen" conditions—are often generated in less than a year, at which point methane-producing bacteria start to break down the waste and release methane (Guermoud et al., 2009).

2.3. Conversion of Landfill Gas into Electricity

2.3.1. Steps for landfill gas electricity generation

The basic steps for landfill gas electricity generation are as follows:

1. Landfill waste is deposited into a landfill area.
2. The landfill waste begins to decay and emit landfill gas, namely methane.
3. The landfill gas rises to the top of the landfill and is collected in pipes located in/around the landfill.
4. The captured landfill gas is then directed to a treatment phase, being dealt with in accordance with its final purpose (ie. burning, electricity etc).
5. Once treated, the gas can then be used as fuel for a combustion engine, in order to create electricity for various purposes.

2.4. Waste-to-Energy?

A group of technologies known as "waste-to-energy" handle trash in order to recover energy in the form of heat, electricity, or alternative fuels like biogas (Kaplan et al., 2009). The term "Waste-to-Energy" encompasses a variety of technologies with varying complexity levels and scales. These include gasification; the thermal treatment of waste in utility-scale incineration plants; the creation of cooking gas from organic waste in household digesters; the collecting of methane gas from landfills; and the co-processing of refuse-derived fuel (RDF) in cement factories. The term "waste-to-energy" is used very broadly in this reference to refer to large-scale municipal (i.e. utility-size) plants that use pyrolysis/gasification, anaerobic digestion, co-processing, and landfill gas collection and incinerator technologies. These five technologies all apply to various waste streams and each has unique features and functions. They must therefore be independently evaluated depending on the relevant local context and waste stream.

2.5. Key Findings and Recommendations

When considering the introduction of Waste-to-Energy technologies, decision makers should consider the following aspects:

i. Waste-to-Energy initiatives should not compete with waste reduction: The creation of municipal solid waste management (MSWM) systems should adhere to the waste hierarchy: preparation for reuse and material recycling should come first, then waste reduction through prevention. Waste-to-Energy initiatives should not compete with waste reduction, reuse, and material recycling strategies because they can be viewed as a complimentary technology for the recovery of energy from remaining non-recyclable MSW components. Waste-to-Energy is a better method of disposal when carried out under controlled circumstances, but it is given low priority in the waste hierarchy (Kaplan et al., 2009).

ii. Waste-to-Energy must achieve high emission standards: There are just a few instances where a complete legal framework for all forms of waste-to-energy exists. The strict emission standards necessary won't be met in jurisdictions where regulations are either nonexistent or cannot be implemented. Low emission levels are not acceptable because they have long-term negative effects on human health (Guermoud et al., 2009). Keep an eye out for global best practices and use internationally accepted standards in the tendering process, making sure that there are monitoring and enforcement measures in place to guarantee compliance.

iii. Waste-to-Energy requires knowledge on waste quantities and characteristics: In many cities, the amount of waste will quadruple over the next 20 years, but there are rarely any consistent waste management strategies that take demographic and social changes into account. Create a waste management strategy for the city that considers the medium-to long-term evolution of trash quantities and details the most pertinent waste streams' characteristics and available treatment methods. To achieve a workable economy of scale, any inter-municipal cooperation should also be taken into account (Gollapalli and Kota, 2018).

iv. Waste-to-Energy builds on an efficient municipal solid waste management (MSWM) system: Only communities with a robust trash collection and transportation infrastructure and a safe ultimate disposal facility may be able to successfully manage waste-to-energy systems. Show and provide documentation that the current waste management system is stable financially and technically (Jaramillo et al., 2005).

v. Waste-to-Energy requires significant financial resources: The sustainable functioning of waste-to-energy plants depends on reliable financing for operation and maintenance. You should think twice before developing a waste-to-energy plant if your municipality can't afford to continue funding its current garbage collection and treatment infrastructure.

vi. Income from energy sales does not cover Waste-to-Energy costs: Waste-to-energy plants have substantial capital and operating expenses that cannot be expected to be covered entirely by the sale of energy at market pricing. Make a realistic projection of the revenue from the sale of energy, and keep an eye out for additional and reliable financing options.

vii. Waste-to-Energy requires qualified staff: Waste-to-energy plants are sophisticated technologies that need specialized personnel and frequent maintenance. They are not simply a simple black box for producing electricity, gas, heat, or steam. Ensure that qualified personnel can be hired and retained and that ongoing training is provided to current employees. Outsourcing should be taken into account for some technical and managerial tasks (Idehai, et al., 2015).

viii. Waste-to-Energy is just a potential part of a functioning municipal solid waste management system: Waste-to-energy plants are not independent technical components and cannot address the current waste issues on their own. Make sure that your waste management system is already planned to include an integrated component for a potential waste-to-energy plant. It is necessary to take backup and emergency capacities into account (Aghdam et al. 2018).

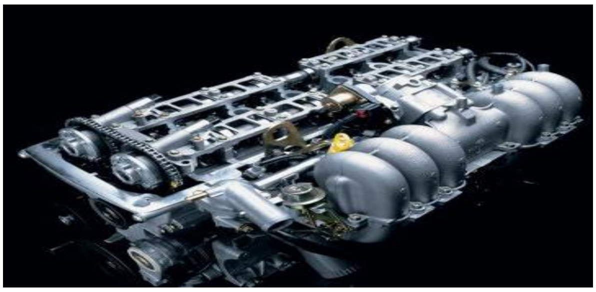

Figure 1. Combustion Engine for Energy Conversion (Kaplan et al., 2009).

The combustion engine is one of the key elements in the process of converting landfill gas into power. A combustion engine, also referred to as a biogas generator, is responsible for turning landfill gas into power. The key distinction is that it uses inverter technology to transform the electricity produced by our co-generators into the kind of electricity we use, whether it is for powering electronic devices, heavy machinery, or the grid. This is coupled with a variable-speed engine that utilizes various fuels of various qualities (e.g., low quality biogas). This fluctuating speed generates raw power, which our electronics transform into smooth DC power and, subsequently, three-phase AC power that is constantly synchronized with the grid (Aghdam et al. 2018).

2.6. Reasons for Converting Landfill Gas to Electricity

Landfill gas is converted to electricity for the following reasons:

- Reduction in greenhouse gas emissions
- Efficient use of waste
- Earn ACCUs
- Reduction of air pollution by offsetting the use of non-renewables
- Relatively cost effective
- Improvement to overall air quality
- Reduction of landfill odour
- Potential Green Energy credits

2.7. Characteristics of Municipal Waste

In a developing or emerging nation, an urban resident produces 100 to 400 kg of MSW annually on average (Figure 2). Different levels of economic development and consumption, as well as the definition of the amount of waste produced, are to blame for this vast range and significant uncertainty (Trapani et al., 2013; Kumar and Sharma, 2014). Some statistics take into account all recycled materials and use the total projected waste generated per person. Others focus just on the trash that is handled by the relevant local authorities, excluding, for instance, valuable materials that are separated and gathered at the source by the unofficial sector. Recycling materials including glass bottles, newspapers, PET bottles, and tins are frequently collected separately before they are added to the formal waste stream, for which the municipality is accountable. Municipalities must therefore manage a "remaining" waste portion that is highly heterogeneous, has high organic content, and has a low calorific value. Planning waste-to-energy solutions, as well as the social impact on the informal sector when a change in the current recycling and primary collection system is proposed, must take these uncertainties in terms of quantity and quality into serious consideration (Kumar and Sharma, 2014).

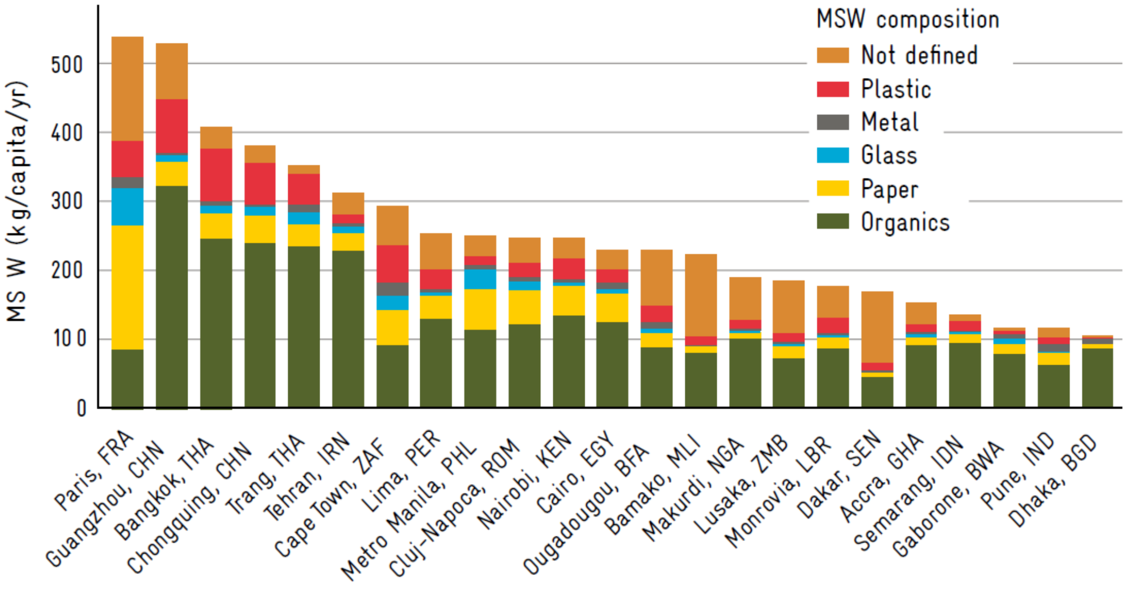

Figure 2. Composition of MSW per capita (kg/capita/yr) in various cities of the world (Kumar and Sharma, 2014).

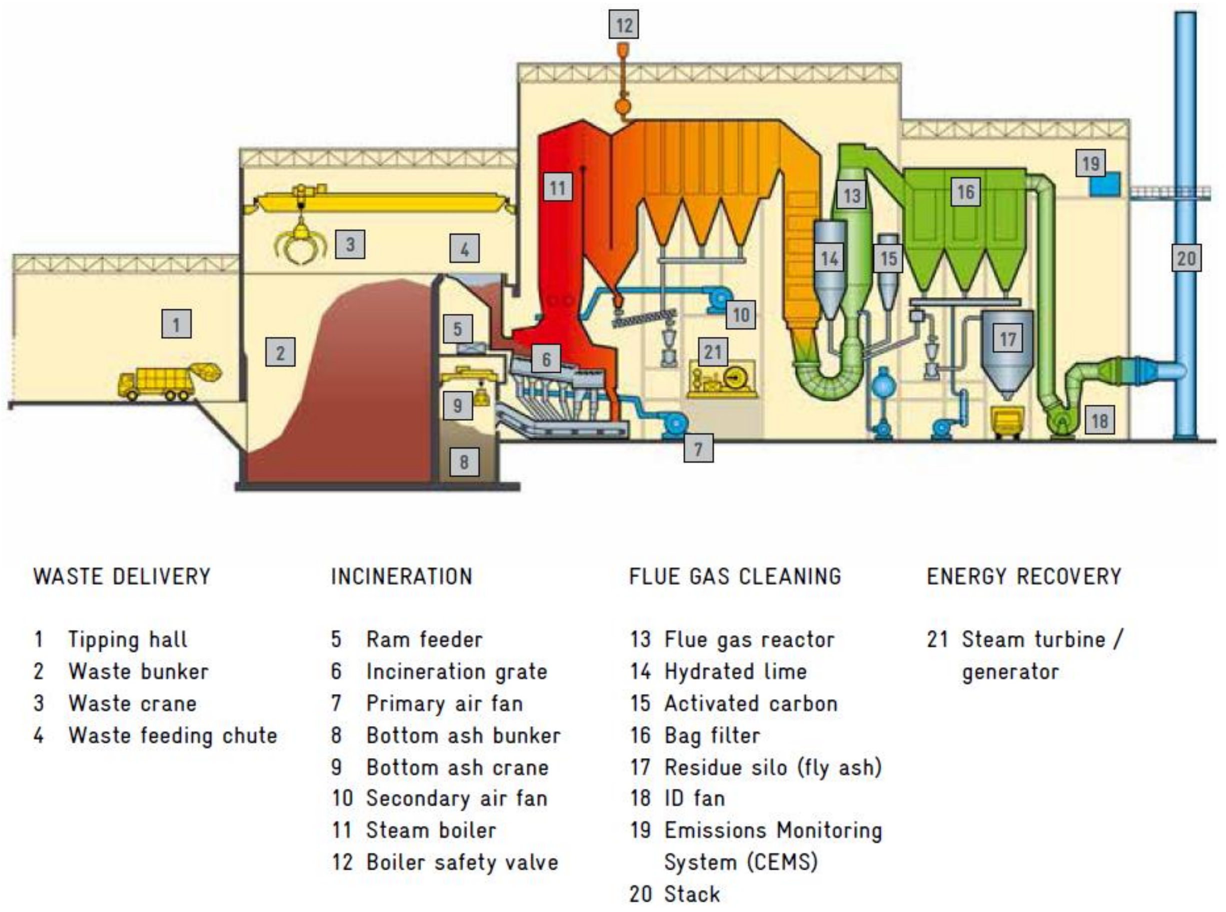

Figure 3. Components of a muncipal solid waste incineration plant with flue gas cleaning. Image (source: Kumar and Sharma, 2014).

3. Waste-To-Energy Technology Option

This section provides an overview of five municipal-scale waste-to-energy technologies: co-processing, anaerobic digestion (AD), landfill gas (LFG), and pyrolysis/gasification (which are also called alternative technologies). The five technologies mentioned above each have a unique role to play in the municipal waste management system. Some technical background information is given, followed by a listing of the suitable waste types and a summary of related operational, environmental, legal, and financial issues. The order of the technologies is based on the perceived demand for advice on these technologies and does not imply any priority or applicability for each technology.

3.1. Anaerobic Digestion for Biogas Production

The degradation of organic materials by microbes in the absence of free oxygen is known as anaerobic digestion (AD). Under controlled circumstances, AD can be utilized to make biogas. AD naturally exists under oxygen-deficient conditions, such as some lake sediments. In order to achieve this, an anaerobic digester, a gas-tight reactor, is utilized to create an environment where microorganisms may convert organic matter, the input feedstock, into biogas and a solid-liquid byproduct known as digestate. When the feedstock is organic waste that has been source separated and is not polluted, the digestate can be used as organic fertilizer. A mixture of several gases called biogas has the potential to provide thermal and/or electrical energy. Methane (CH_4), a flammable gas, is the primary energy component of biogas, with concentrations ranging from 50 to 75 percent depending on feedstock and operating conditions. The heating value of biogas is roughly two-thirds that of natural gas (5.5 to 7.5 kWh/m^3) due to its lower methane content. In poor nations, AD employing small-scale digesters has a long history of harnessing the energy component of organic leftovers in rural settings. Agriculture provides the majority of the feedstock inputs, particularly animal manure, which may be used effectively at small scales and is quite simple to operate. At the municipal level, AD is getting more consideration as a potential solution for waste-to-energy recovery in urban settings. However, the operation of biogas plants from heterogeneous MSW is a big challenge in terms of operational, safety and financial requirements. As a consequence there are very few successful examples of biogas from MSW in developing countries. Being able to ensure a continuously well-separated organic waste component is a significant obstacle to successful AD operations. The success of AD at larger scales is frequently hampered by the frequent mixing of organic waste with inorganic materials, such as plastics, metals, and other pollutants, in many nations. Small-scale biogas facilities are an option and can be effectively used in impoverished nations, as opposed to other waste-to-energy plants.

3.2. Description of Technology

A large number of different anaerobic digester designs exist worldwide with varying levels of complexity. According to Kaplan, Decaroli and Thorneloe (2009), anaerobic digester can be classified by:

- Mode of feeding: Batch or continuous feeding
- Temperature range: There are three temperature ranges: psychrophilic (25°C), mesophilic (35–48°C), and thermophilic (> 50°C), with the latter two being the only ones deemed economically viable. When there is a high risk of infection, thermophilic environments are advised. To inactivate pathogens for mesophilic systems, alternative methods include pasteurization at 70 °C for one hour or thermophilic composting (Karanjekar, 2015).
- Reactor type: While plug-flow and batch digesters are utilized for solid feedstock, continuously stirred tank reactors are frequently employed for liquid feedstock such as catering waste, wastewater, or industrial sludge from food processing. The utilization of solid feedstock in continuously stirred tank reactors can be accomplished by dewatering the feedstock (Lou and Nair, 2009).
- Number of stages: One to multi-stage digestion is possible.
- In a combined heat and power plant, biogas can either be utilized directly to generate heat or transformed into heat and electricity, the latter process often taking place after desulfurization and drying. Another choice is to transform biogas into biomethane, which can replace natural gas and has a methane content of about 98% (Loening, 2003). Figure 8: The production of biogas through anaerobic digestion of organic waste and manures is depicted in Figure 8. The biogas produced may be used, for instance, in a combined-heat-and-power (CHP) generator.

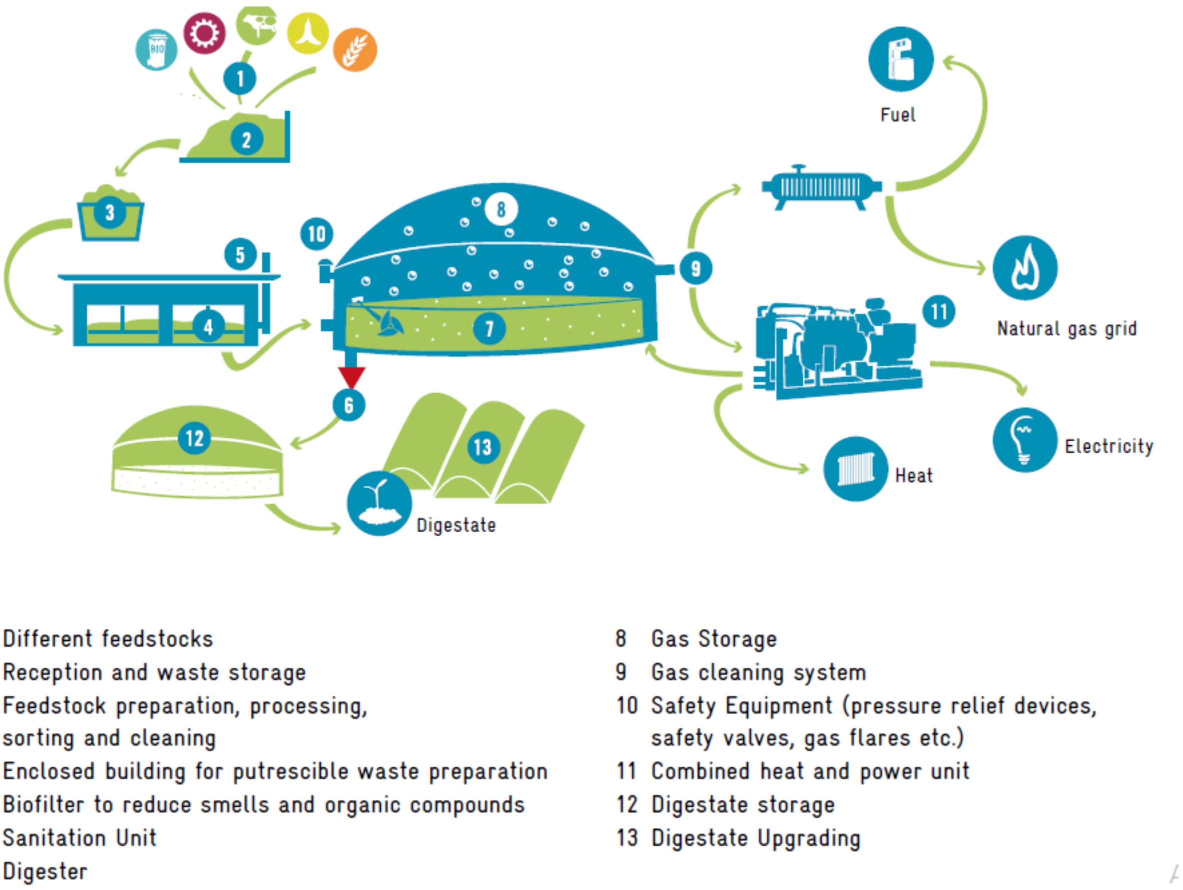

Figure 4. Components and end-uses of an anaerobic digestion plant. Image source: Fachverband biogas

3.3. Suitable Waste

Only organic matter, or biomass, can be processed by an anaerobic digester. Because these are broken down gradually by an anaerobic digester, the amount of fibrous material, such as hemicellulose and lignin, found, for example, in straw and woody plants, should typically be quite low (Taherzadeh, 2009). It is feasible to employ specifically produced energy crops, such as maize, for the production of biogas in addition to using organic "waste" biomass such as agricultural residues or organic fractions of MSW (Themelis and Ulloa, 2007). As a result, this is not the topic of this guide, which instead discusses anaerobic digesters that solely process organic waste from municipal garbage. However, this could result in potential conflicts with food production. The addition of inorganic or dangerous materials is not desired in the process and can hinder microbial deterioration, block operation, for example by clogging pipes with plastic materials, and/or restrict the digestate's suitability for use as organic fertilizer. An appropriate source of anaerobic digester fuel is municipal organic waste, such as source-separated home, market, and garden trash. Additionally, co-digestion with agricultural leftovers, wastewater treatment plant sludge, or organic industrial or commercial waste can boost the availability of feedstock and, as a result, the economic viability of the process. Using household bio-waste is more advanced than using energy crops, commercial and industrial wastes, animal byproducts, or vegetable byproducts as feedstock (Taherzadeh, 2009). This is a result of the feedstock's fluctuating composition throughout the course of the year and the potential presence of significant contaminants. The anaerobic digester produces variable amounts of methane and energy depending on the feedstock (indicative examples in Table 1).

Table 1. Indicative examples of methane and energy yields of selected organic waste feedstock through anaerobic digester with methane yields in norm m^3 (Nm^3, at 0 °C, 1.01325 bar and relative gas humidity of 0%) per ton wet weight (t) of feedstock and 37.8 MJ per Nm^3 CH_4 (higher heating value).

Feedstock	Methane yield [Nm^3 CH per t	Energy yield [MJ per t_{wet}]
Municipalities		
Wastewater	15	570
Kitchen and garden waste	40-100	1510-3780
Industries		
Fruit waste	60	2270
Slaughterhouse waste	50	1890
Agriculture		
Cattle manure	32	1210
Grass	90	3400

3.4. Operational Aspects

Important operational aspects include the following:

- Availability and composition of organic waste feedstock: Seasonal variations in the availability of agricultural goods and their residues are the main factors that affect the composition and quantities of organic waste. Anaerobic digesters need to be planned with this in mind, and this should include dimensioning as well as the potential for feedstock storage facilities when feedstock availability exceeds plant capacity (U.S.EPA, 2011).
- Temperature: If there are no other limiting factors, microorganisms thrive and reproduce more quickly at higher temperatures. Most of the time, a mesophilic temperature range between 35 and 48 °C is thought to be the most stable. In general, operation at higher temperatures in the thermophilic range > 50 °C requires heating and insulation but can help remove pathogens and reduce reactor volumes. Small-scale psychrophilic anaerobic digesters have been successfully used in colder locations (Vaverkova and Adamcova, 2015), but larger scale digesters may not be economically feasible due to the demand for heating and insulation.
- Organic loading rate (OLR): OLR quantifies the amount of feedstock which a specific reactor can degrade per unit of time.
- Carbon: Nitrogen ratio (C:N): For anaerobic digesters, the relative abundance of carbon and nitrogen should be between 16 and 25, which is a crucial characteristic for microbial growth.

3.5. Capturing of Landfill Gas

Different from the other waste-to-energy technologies described in this handbook is Landfill Gas (LFG) Capture. It is to be viewed as a crucial element in partially minimizing the damaging effects of operating sanitary landfills on the environment (SLF). In underdeveloped nations, sanitary landfilling is a widely used and approved method and, in many instances, the only way to properly process and store the gathered garbage (Willumsen and Barlaz, 2011). SLF has detrimental long-term environmental effects, such as the emission of methane landfill gas with a significant potential for global warming into the atmosphere, despite being an improvement over uncontrolled and open dumping of compounds. Others include the waste's loss of valuable resources when it is landfilled and the presence of noxious and toxic substances. The anaerobic digestion of organic matter in the landfill body, which can be thought of as an oversized bioreactor, produces the methane in LFG (Yang et al., 2015). The capturing of methane gas is essential in order to reduce greenhouse gas emissions from landfill sites into the atmosphere. This is possible through LFG capture. However, significant losses occur in the start-up phase of a landfill site before the methane capturing system is installed and in operation (Yechiel and Shevah, 2016). When in operation, it is still not possible to capture all of the gas emitted by the landfill.

3.6. Technology Description

LFG is ideal as a fuel for the production of heat or power, combined heat and power generation, or as a fuel for transportation because it contains 45–55% methane gas. CO_2 makes up the majority of the remaining material. The following variables affect LFG yield:

- How fresh waste is placed and compacted;
- Level of compacting and height of the individual layers;
- Water content in the landfill;
- Climate;
- Technical features for capturing the methane gas in the SLF.

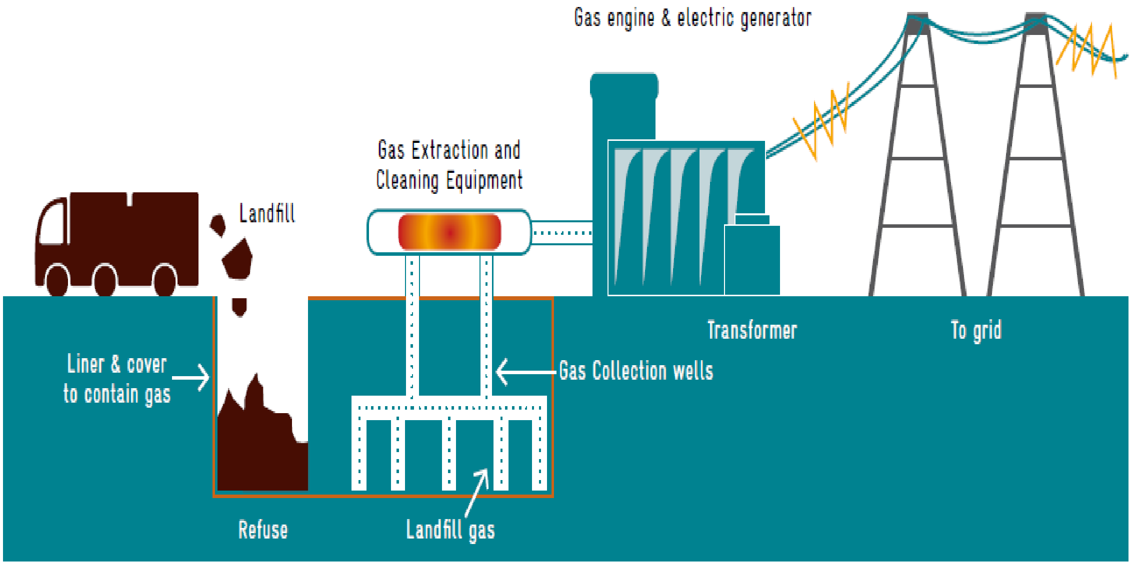

Figure 5. Components of landfill gas capturing system with electricity production (Aronica et al., 2009).

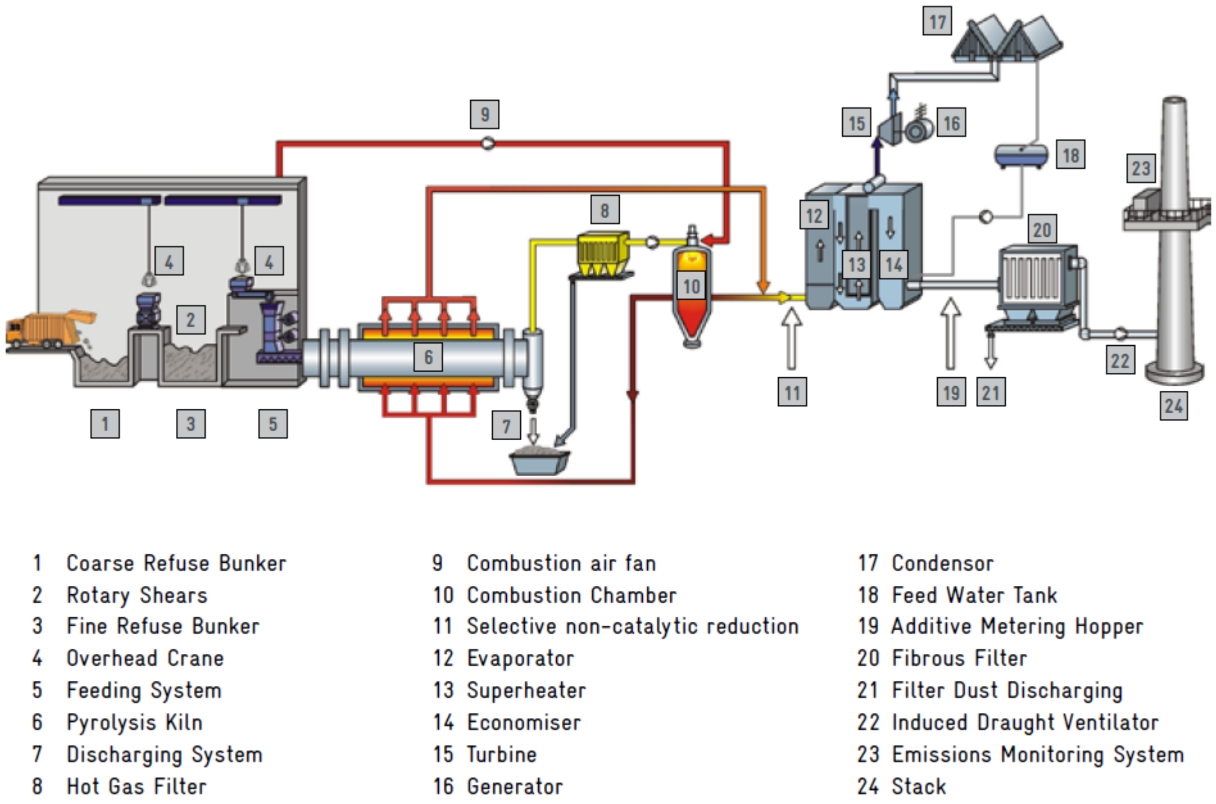

Figure 6. Components of a pyrolysis plant for specific solid waste treatment (U.S.EPA, 2011).

3.7. Composition of Waste

- Separation of MSW at the source in households is the best precondition for recycling and also for waste-to-energy. Hazardous & bulky mineral waste should be collected and treated separately.
- As already mentioned, for anaerobic digestion separate collection of organic waste is a necessity. Anaerobic digestion is not an option if separately collected waste is mixed with mineral or hazardous waste, even in small amounts.
- If MSW is regularly mixed with hazardous and mineral fractions the suitability of each waste-to-energy technology must be assessed frequently. Measures to improve waste separation at source should be initiated (e.g. separate collection and treatment of construction & demolition waste and batteries).
- Landfill gas collection remains relevant where sanitary landfills contain significant levels of organic waste.

3.8. Calorific Value of MSW for Thermal Processes, Organic Content

- For incineration and co-processing, autothermic combustion, or self-sustaining burning without additional fuel, MSW must be ensured year-round. Oil, gas, and other fuels should not be co-fired because it is expensive and should only be done in an emergency or to start the combustion process. Calorific value is one criterion for determining if MSW is acceptable for incineration and co-processing. The calorific value is decreased by trash from the kitchen and garden that has a high mineral content (from glass, ash, building and demolition debris), a high metal content, or both. All combustion processes are suitable for waste-to-energy projects if their calorific values are greater than 8 MJ/kg.
- Incineration technologies with an advanced integrated drying stage are able to combust wet MSW with a calorific value of about 7 MJ/kg. For co-processing the minimum acceptable humidity should be clarified and drying technologies assessed before starting a waste-to-energy project.
- The minimal permissible humidity for all combustion technologies should be clarified, and drying technologies should be evaluated if the calorific value is less than 7 MJ/kg due to humidity. Before pursuing waste-to-energy options, general waste management should be addressed when mineral waste is the primary cause of the low calorific value.
- The LCV for thermal processes cannot be directly compared with LFG collection and anaerobic digestion. However, the energy content of organic feedstock for an anaerobic digestor has an impact on the energy content of the biogas yield. Higher energy content feedstocks can increase the quality of the biogas. The efficiency of landfill gas collection is dependent on the existing landfill conditions, including the proportion of organic waste deposited and the way this is layered.

4. Collecting and Treating Landfill Gas

Instead of escaping into the air, LFG can be captured, converted and used as a renewable energy resource. Using LFG helps to reduce odors and other hazard associated with LFG emissions. This prevents methane from migrating into the atmosphere and contributing to local smog and global climate change. In addition, LFG energy projects generate revenue and create jobs in the community and beyond.

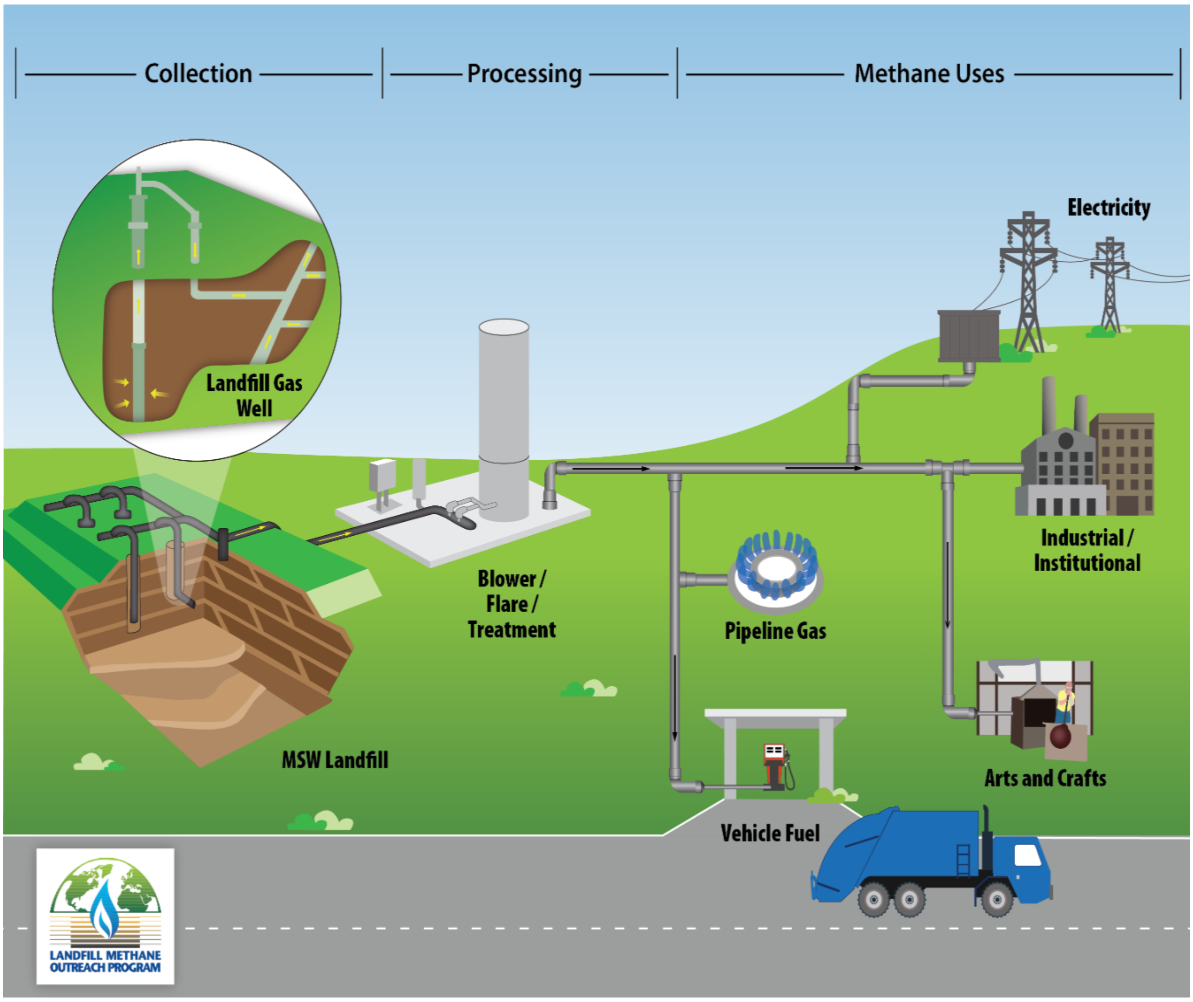

Figure 7. The Collection and Processing of LFG to Produce Methane for Multiple uses.

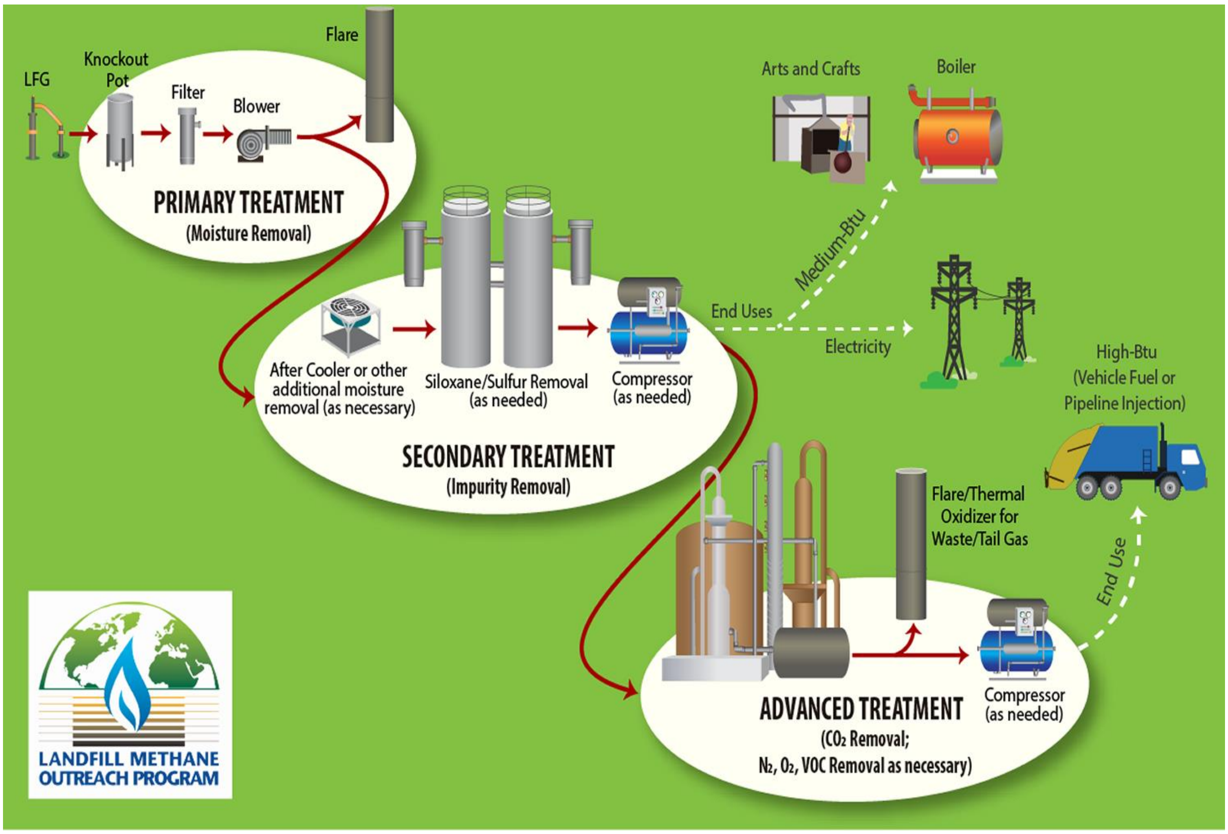

Figure 8. The three stages of LFG treatment.

First, LFG is collected through vertical and horizontal piping buried in an MSW landfill. The LFG is then processed and treated for use. Figure 7 shows potential end uses of LFG including industrial/institutional uses, arts and crafts, pipeline gas, and vehicle fuel.

The gas goes via a knockout pot, filter and blower as part of the primary treatment process to remove moisture (Figure 8). The use of an after cooler or another method of additional moisture removal (if required), followed by the removal of siloxane and sulfur, and compression, constitutes secondary treatment (as needed). Following the removal of impurities during the secondary treatment stage, LFG can be used to produce electricity or as a medium-Btu fuel for boilers or other crafts. Advanced Treatment compresses the LFG into a high-Btu gas that can be utilized as car fuel or pumped into a gas pipeline while also removing extra contaminants (CO_2, N_2, O_2, and VOCs). Waste or tail gas is sent to a thermal oxidizer or flare.

4.1. Basic LFG Collection and Processing System

LFG is removed from landfills by utilizing a blower/flare (or vacuum) system and a network of wells. Depending on the gas's intended use, this system routes the gathered gas to a central location where it can be processed. Here, the gas can either be flared or utilised profitably in LFG energy production.

4.2. Landfill Gas Energy Project Types

There are numerous ways to transform LFG into energy. The following are three major categories into which various LFG energy project types are divided: electricity generation, direct use of medium-Btu gas, and renewable natural gas. Under each project type are descriptions of the project technologies.

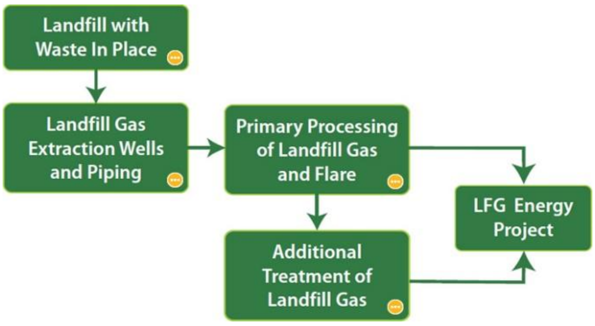

Figure 9. Flowchart of a basic LFG collection and processing system.

4.3. Electricity Generation

Electricity is produced by about 69 percent of the LFG energy plants that are currently in operation. Reciprocating internal combustion engines, turbines, micro-turbines, and fuel cells are just a few of the technologies that can be utilized to produce electricity for on-site use or for sale to the grid. Due to its relatively low cost, high efficiency, and size ranges that complement the gas output of many landfills, the reciprocating engine is the most commonly used conversion technology for LFG energy applications. Larger LFG energy projects often use gas turbines, while specialized applications and smaller LFG volumes typically use micro-turbines. Plants that employ LFG to create both electricity and thermal energy, typically in the form of steam or hot water, are referred to as cogeneration or combined heat and power (CHP) projects. At industrial, commercial, and institutional operations, a number of cogeneration projects using engines or turbines have been installed. This project type can be particularly alluring due to its efficiency improvement, which can be used to capture thermal energy in addition to electricity generation.

5. Conclusion

Waste to energy; review on the development of land fill gas for power generation in Sub-Saharan Africa has been achieved. It was discovered that landfill gas is a workable substitute for fossil fuel and other fuel sources for the production of sustainable energy (electricity). It reduces fugitive landfill gas and also greenhouse gas emissions from fossil fuel power plants. Gas emissions from landfills are valuable waste that ought to be recovered, especially in light of the energy component of the methane. Improvements in new generator technology have led to a change in how electricity is produced from landfill gas. Innovations in power generation have increased its effectiveness and environmental performance. However, the new technology still needs to demonstrate its potential to provide energy for a sustainable future especially within the Sub-Saharan Africa. Landfill gas (LFG) is considered a suitable source of energy by both Australia and the USA under regulations and a set of government funds that have been implemented to improve electricity generation from renewable sources. The growth of renewable energy has received support from both governments. Nevertheless, the Australian government has to pay closer attention to landfill gas power generation and learn from the US experience. Support for green energy from the government and society will have an impact on investment, which promotes the development of innovative technologies. To enhance the performance of green power in the environmental, social, and economic sectors, more research on LFG production technology and power generation is needed.

Author Contributions

The percentage of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

	H.Ö.	U.Ş
C	50	50
D	50	50
S	50	50
DCP	50	50
DAI	50	50
L	50	50
W	50	50
CR	50	50
SR	50	50

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The authors declare that there is no conflict of interest.

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References

Aghdam EF, Fredenslund AM, Chanton J, Kjeldsen P, Scheutz C. 2018. Determination of gas recovery efficiency at two danish landfills by performing downwind methane measurements and stable carbon isotopic analysis. Waste Manag, 73: 220-229. DOI: 10.1016/j.wasman.2017.11.049.

Aguilar-Virgen QP, Taboada-González S, Ojeda-Benítez M. 2014. Power generation with biogas from municipal solid waste: prediction of gas generation with in situ parameters. Renew Sust Energy Rev, 30: 412-419. DOI: 10.1016/j.rser.2013.10.014.

Aronica S, Bonanno A, Piazza V, Pignato L, Trapani S. 2009. Estimation of biogas produced by the landfill of palermo, applying a gaussian model. Waste Manag, 29: 233-239. DOI: 10.1016/j.wasman.2008.02.026.

Barbaro S, Bonanno A, Boscia ML, Rizzo G, Aronica S. 2009. The impact of landfills on the air quality of towns – A simple heuristic model for the city of Palermo. Int J Environ Pollut, 36: 287-304. DOI: 10.1504/IJEP.2009.021833.

Bogner J, Spokas K. 1993. Landfill CH4: Rates, fates, and role in global carbon cycle. Chemosphere, 26: 369-386. DOI: 10.1016/0045-6535(93)90432-5.

Calabro PS, Gorib M, Lubello C. 2015. European trends in greenhouse gases emissions from integrated solid waste management. Environ Technol, 36(16): 2125-2137. DOI: 10.1080/09593330.2015.1022230.

Calabro PS, Orsi S, Gentili E, Carlo M. 2011. Modelling of biogas extraction at an Italian landfill accepting mechanically and biologically treated municipal solid waste. Waste Manag Res, 29: 1277-1285. DOI: 10.1177/0734242X11417487.

Calabro PS. 2009. Greenhouse gases emission from municipal waste management: The role of separate collection. Waste Manage, 29(7): 2178-2187. DOI: 10.1016/j.wasman.2009.02.011.

Christensen TH, Manfredi S, Knox K. 2011. Landfilling: Reactor landfills. In Solid Waste Technology Management, ed. H. Thomas Christensen, John Wiley and Sons, New York, US, pp: 772-787.

Cossu R, Muntoni A. 1997. Biogas emission measurement using static and dynamic flux chambers and infrared method. Sixth International Waste Management and Landfill Symposium, Cagliari, Italy, pp: 97.

Czepiel PM, Shorter JH, Mosher B, Allwine E, McManu JB, Harriss RC, Kolb CE, Lamb BK. 2003. The influence of atmospheric pressure on landfill methane emissions. Waste Manag, 23: 593-598. DOI: 10.1016/S0956-053X(03)00103-X.

Ehsan FA, Anders MF, Jeffrey C, Peter K, Charlotte S. 2019. Determination of gas recovery efficiency at two Danish landfills by performing downwind methane measurements and stable carbon isotopic analysis. Waste Manage, 73: 220-229. https://doi.org/10.1016/j.wasman.2017.11.049.

Emkes H, Coulon F, Wagland S. 2015. A decision support tool for landfill methane generation and gas collection. Waste Manag, 43: 307-318. DOI: 10.1016/j.wasman.2015.07.003.

Fecil B, Heroux M, Guy C. 2003. Development of a method for the measurement of net methane emission from MSW landfills. Ninth International Waste Management and Landfill Symposium, October 6-10, 2003, Cagliari, Italy.

Friedrich E, Trois C. 2010. GHG accounting and reporting for waste management – A South African perspective. Waste Manag, 30: 2336-2346. DOI: 10.1016/j.wasman.2010.05.016.

Gollapalli M, Kota H. 2018. Methane emissions from a landfill in north-east India: Performance of various landfill gas emission models. Environ Pollut, 234: 174-180. DOI: 10.1016/j.envpol.2017.11.064.

Guermoud N, Ouadjnia F, Abdelmalek F, Taleb F. 2009. Municipal solid waste in Mostaganem city (Western Algeria). Waste Manag, 29(2): 896-902. DOI: 10.1016/j.wasman.2008.03.027.

Idehai IM, Akujieze CN. 2015. Estimation of landfill gas and its renewable energy potential in Lagos, Nigeria. Int J Energy Environ Eng, 6: 329-343. DOI: 10.1007/s40095-015-0178-9.

Ishigaki T, Yamada M, Nagamori M, Ono Y, Inoue Y. 2005. Estimation of methane emission from whole waste landfill site using correlation between flux and ground temperature. Environ Geol, 48: 845-853. DOI: 10.1007/s00254-005-0008-0.

Jaramillo P, Matthews HS. 2005. Landfill-gas-to-energy projects: Analysis of net private and social benefits. Environ Sci Tech, 39: 7365-7373. DOI: 10.1021/es050633j.

Johari A, Ahmed SI, Hashim H, Alkali H, Ramli M. 2012. Economic and environmental benefits of landfill gas from municipal solid waste in Malaysia. Renew Sust Energy Rev, 16(5): 2907-2912. DOI: 10.1016/j.rser.2012.02.005.

Kaplan PO, Decarolis J, Thorneloe S. 2009. Is it better to burn or bury waste for clean electricity generation? Environ Sci Tech, 43: 1711-1717. DOI: 10.1021/es802395e.

Karanjekar RV, Bhatt A, Altouqui S, Jangikhatoonabad N, Durai V, Sattler ML, Hossain MDS, Chen V. 2015. Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: The CLEEN model. Waste Manag, 46: 389-398. DOI: 10.1016/j.wasman.2015.07.030.

Kumar A, Sharma MP. 2014. Estimation of GHG emission and energy recovery potential from MSW landfill sites. Sust Energy Tech Assess, 5: 50-61. DOI: 10.1016/j.seta.2013.11.004.

Loening A. 2003. Predictions and projections; looking at the power generation potential of landfill gas. Waste Management World International Solid Waste Association, Copenhagen, Denmark.

Lou XF, Nair J. 2009. The impact of landfilling and composting on greenhouse gas emissions – A review. Bioresource Tech, 100: 3792-3798. DOI: 10.1016/j.biortech.2008.12.006.

Niskanen A, Värri H, Havukainen J, Uusitalo V, Horttanainen M. 2013. Enhancing landfill gas recovery. J Clean Produc, 55: 67-71. DOI: 10.1016/j.jclepro.2012.05.042.

Salihoglu G, Salihoglu NK, Ucaroglu S, Banar M. 2018. Food loss and waste management in Turkey. Bioresour Tech, 248(Part A): 88-99. DOI: 10.1016/j.biortech.2017.06.083.

Scarlat N, Motola V, Dallemand JF, Monforti-Ferrario F, Mofor L. 2015. Evaluation of energy potential of municipal solid waste from African urban areas. Renew Sust Energy Rev, 50: 1269-1286. DOI: 10.1016/j.rser.2015.05.067.

Scharff H, Jacobs J. 2006. Applying guidance for methane emission estimation for landfills. Waste Manag, 26(4): 417-429. DOI: 10.1016/j.wasman.2005.11.015.

Scheutz C, Fredenslund AM, Chanton J, Pedersen GB, Kjeldsen P. 2011. Mitigation of methane emission from Fakse landfill using a biowindow system. Waste Manag, 31: 1018-1028. DOI: 10.1016/j.wasman.2011.01.024.

Taherzadeh MJ. 2009. Waste to wealth. Vetenskap för Pprofes, 10: 38-73.

Themelis NJ, Ulloa PA. 2007. Methane generation in landfills. Renew Energy, 32(7): 1243-1257. DOI: 10.1016/j.renene.2006.04.020.

Trapani DD, Bella GD, Viviani G. 2013. Uncontrolled methane emissions from a MSW landfill surface: Influence of landfill features and side slopes. Waste Manag, 33: 2108-2115. DOI: 10.1016/j.wasman.2013.01.032.

Troschinetz AM, Mihelcic JR. 2009. Sustainable recycling of municipal solid waste in developing countries. Waste Manag, 29: 915-23. DOI: 10.1016/j.wasman.2008.04.016.

Tsai WT. 2007. Bioenergy from landfill gas (LFG) in Taiwan. Renew Sust Energy Rev, 11(2): 331-344. DOI: 10.1016/j.rser.2005.01.001.

U.S.EPA. 2011. Operating gas engines at landfill sites in new LFGTE countries. URL: https://www.epa.gov/sites/ production /files/2016-06/documents/pirker.pdf (access date: December 29, 2017).

Vaverkova M, Adamcova D. 2015. Long-term temperature monitoring of a municipal solid waste landfill. Polish J Environ Stud, 24(3): 1373-1378. DOI: 10.15244/pjoes/29940.

Weitz KA, Thorneloe SA, Nishtala SR, Yarkosky S, Zannes M. 2002. The impact of municipal solid waste management on greenhouse gas emissions in the United States. J Air Waste Manag Assoc, 52(9): 1000-1011. DOI: 10.1080/10473289.2002.10470843.

Willumsen H, Barlaz MA. 2011. Landfilling: gas production, extraction and utilizatin. In Solid Waste Technology Management, Editor: Christensen, Blackwell Publishing, Malaysia, pp: 1022.

Yang L, Chen ZL, Zhang X, Liu YY, Xie Y. 2015. Comparison study of landfill gas emissions from subtropical landfill with various phases: A case study in Wuhan, China. J Air Waste Manag Assoc, 65(8): 980-986. DOI: 10.1080/10962247.2015.1051605.

Yechiel A, Shevah Y. 2016. Optimization of energy generation using landfill biogas. J Energy Stor, 7: 93-98. DOI: 10.1016/j.est.2016.05.002.

Zuber MJS, Ali SF. 2015. Greenhouse effect reduction by recovering energy from waste landfills in Pakistan. Renew Sust Energy Rev, 44: 117-131. DOI: 10.1016/j.rser.2014.12.028.