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Review

Prospects of Waste Incineration for Improved Municipal Solid Waste (MSW) Management in Ghana—A Review

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Abstract: The per capita municipal solid waste (MSW) generation per day in Ghana is estimated to be 0.47 kg/person/day, which translates to over 14,000 tonnes of solid waste generation daily. The disposal and management of this amount of solid waste has been challenging worldwide, and in Ghana, this is evident with the creation of unsanitary dumping sites scattered across most communities in the country, especially urban communities. The indiscriminate disposal of solid waste in Ghana is known to cause flooding, the pollution of water bodies, and the spread of diseases. The purpose of this review is to highlight the prospects of waste incineration with energy recovery as a waste-to-energy (WtE) technology which has contributed immensely to the disposal and management of MSW in nations worldwide (especially developed ones). The review indicates that waste incineration with energy recovery is a matured waste-to-energy technology in developed nations, and there are currently about 492 waste incineration plants in operation in the EU, over 77 in operation in about 25 states in the USA, and about 1900 in operation in Japan. Waste incineration with energy recovery is also gradually gaining prominence in developing nations like China, Brazil, Bangladesh, Nigeria, Indonesia, and Pakistan. The adoption of waste incineration with energy technology can reduce Ghana's overdependence on fossil fuels as primary sources of energy. It is, however, recommended that a techno-economic assessment of proposed waste incineration facilities is performed considering the MSW generated in Ghana. Additionally, it is also recommended that the possibility of incorporating the use of artificial intelligence technology into the management of MSW in Ghana be investigated.

Keywords: municipal solid waste; waste to energy; waste incineration; disposal; management; thermal power plant; fossil fuels; primary sources of energy

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1. Introduction

A World Bank report [1] estimated that 2.01 billion tonnes of municipal solid waste (MSW) is generated worldwide annually, and this is expected to increase to about 3.4 billion tonnes by the year 2050. The World Energy Council [2] also estimates that the urban MSW generation per capita (in kg/day) in Africa is 0.65, and this is expected to increase to 0.85 kg/day by the year 2025. The increase in MSW generation is attributed to an increase in population growth, global industrialisation, enhanced standard of living, and rapid urbanisation [3–6]. The disposal and management of such copious amounts of MSW have been challenging worldwide. In Ghana, the situation has become the nemesis of successive governments, and this is evident with open landfill sites created in most communities, especially urban communities, all over the country. A study [7] indicates that flooding in most areas in Ghana (especially in Accra, the capital city of Ghana) is as a result of the obstruction of drainage systems by MSW, which is disposed indiscriminately. The study also reported that in the year 2011 alone, flooding in Accra claimed fourteen (14) lives, about 17,000 people lost their homes, and about 43,000 people were affected; also, there were damages to bridges, roads, and waterways. The flooding in Accra and most parts of the country has become a perennial problem during rainy seasons in the country. Furthermore, the indiscriminate disposal of MSW has been a threat to both human health and environmental issues such as air pollution, water quality, and issues that are associated with land toxicity. The disposal and management of these enormous amounts of solid waste is the greatest challenge faced by the present generation and is expected to be the same for future generations, if adequate measures are not put in place [2].

Meanwhile, Ghana has been struggling to meet its energy demand in recent years, because of the shortfall of electricity generation in the country; this always forces the Electricity Company of Ghana to embark on load shedding exercises to customers from time to time. The energy mix in Ghana is dominated by the burning of fossil fuels (which constitutes about 61% of total electricity generated) in various thermal power plants that are operated by the Volta River Authority and other independent power producers [8]. Waste incineration with energy recovery is a waste-to-energy (WtE) technology which has been established to be an appropriate method of dealing with MSW worldwide [9]. It is estimated that there are about 77 waste incineration facilities in operation in the USA [10], about 492 in the EU [11], and about 1900 operating in Japan [12]. The aforementioned developed nations have adopted the use of the waste incineration technology as an attractive means of disposing and managing non-recyclable and non-reusable waste not only because it minimizes the risks in disposing large quantities of this waste into landfill sites, but also due to the fact that useful energy (in the form of electricity and heat) can be recovered.

Can energy recovery from the disposal and management of MSW using WtE facilities be integrated into the energy mix of developing countries, including Ghana, to diversify the traditional means of energy generation? With the improvements made in the disposal and management of MSW in developed nations via the use of waste incineration facilities, why are developing countries including Ghana not taking advantage of these technologies? MSW as fuel is heterogeneous in nature, unlike fossil fuels like coal and others; as such, a simple import of the WtE technology to a different location is not usually successful. This is because the composition of MSW varies from one location to another throughout the globe depending on the geographical area, variations due to climate conditions and seasonality, consumption patterns, as well as geographical locations [13,14].

There are several studies which have explored and confirmed that there is great potential in generating energy from solid waste generated in Ghana [15–24]. Although the aforementioned studies considered either the thermochemical conversion or biological conversion methods of WtE technologies, the thermochemical conversion methods studied were only limited to either gasification or pyrolysis. This review research work, therefore, seeks to highlight contributions that can be made through employing waste incineration with energy recovery as a sustainable WtE technology in the disposal and management of MSW in Ghana. The research question that this review paper seeks to answer is as follows: how has the use of waste incineration with energy recovery contributed to electricity generation in nations worldwide? This review work forms part of a research investigation with a broader aim of proposing the optimal integration of WtE in Ghana and focuses on waste characterization, WtE technologies, and the status of waste incineration with energy recovery as a mature WtE technology in the disposal and management of MSW worldwide.

2. Overview of Waste and WtE Technologies

2.1. Overview of Waste

There are numerous definitions offered by dictionaries on the term "waste". An important but simple definition of this term from the Merriam-Webster Dictionary includes, "refuse from places of human or animal habitation, damaged, defective, or superfluous material produced by a manufacturing process", etc. Waste is also defined as anything which does not have any use for the holder. This definition of waste does not, however, include sewage effluent, radioactive waste, and emissions into the atmosphere. The issue of waste disposal and its management is one that has plagued nations worldwide, regardless of their socio-economic standing or reputation.

According to the World Bank [1], although there are significant variations in waste generation by region, waste generation can be viewed as a function of wealth. A report estimated that in 2018, global waste generation stood at 2.01 billion tonnes per year. However, this is expected to increase to 3.4 billion tonnes per annum by the year 2025. Generally, it can also be observed that areas with higher rates of urbanisation and economic development tend to have a greater amount of solid waste generation compared to areas with lower rates of economic development. Factors such as local climate and public habits also influence waste generation rates [25]. This trend can clearly be observed in Figure 1, which illustrates the percentage of waste generated by lower, lower middle, upper middle, and high-income countries in the world. Tchobanglous G. et al. [26] identified seven key issues that need to be considered in discussing solid waste management.

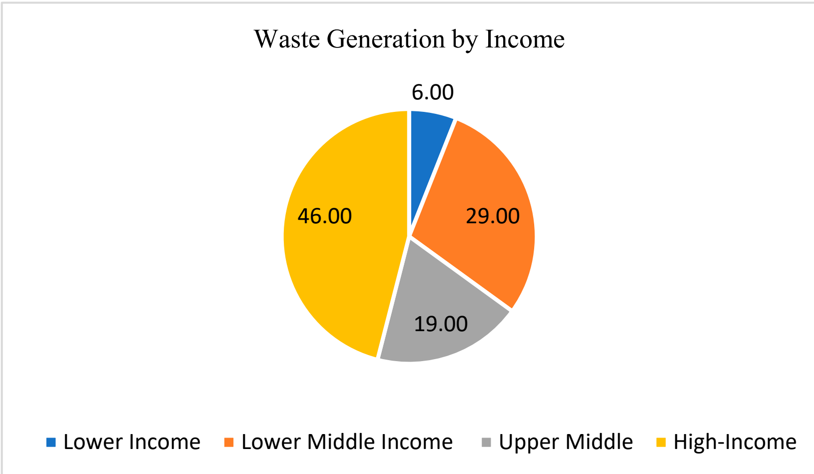

Figure 1. Waste generation by income [25].

Waste can broadly be categorized into two groups, organic and inorganic. Organic waste is biodegradable waste, and this is waste that basically comes from plants, animals, or food. Inorganic wastes, on the other hand, are non-biodegradable wastes, and these include plastics, glass, papers, and metals [27]. Waste can also be classified either as biodegradable or non-biodegradable. Biodegradable waste (also referred to as putrescible waste) is waste that is generated from sources like plants or animal sources and is degradable or can be broken down by organisms; examples are food leftovers, faecal matter, trimmings from lawn mowing, etc. Non-biodegradable waste (also referred to as imputrescible waste), is waste that is usually from materials that are not broken down naturally by organisms; examples include metals, leather, plastics, papers, etc. [28]. Waste can also be classified as either being combustible or non-combustible waste when considering the incineration of the waste. Combustible wastes are usually organic wastes, and some other inorganic wastes that are burnable; examples include papers, textiles, plastics, etc., whereas non-combustible wastes include glass, metals, ceramics, etc., and this waste cannot burn [29,30].

The definition of municipal solid waste (MSW) varies from one literature to the other. However, one of the best definitions is that given by the United States National Research Council [31]; MSW is defined as the "solid portion of waste (not classified as hazardous or toxic) generated by households, commercial establishments, public and private institutions, government agencies and other sources". This stream of waste consists of food and yard waste and a plethora of durable and non-durable products, as well as packaging. MSW is also defined as non-homogeneous materials that are generated through anthropogenic activities by households as well as in commercial places within a municipality. This comprises waste like plastic, leather, metals, glass, as well as waste that is generated from food industries (like hotels, restaurant, hostels, and households), and others which are inorganic [32]. MSW, however, excludes waste such as automobile bodies, municipal sludges, non-hazardous industrial process waste, combustion ashes, construction, and demolition waste. The amount of MSW generated can be viewed as the sum of waste collected and disposed of on behalf of the municipal authorities.

Waste composition is considered paramount in the identification of the best practice to be adopted for its disposal and management. A study [33] indicates that MSW composition is largely influenced by factors such as cultural conditions, lifestyles, literacy rates, economic status, food habits, as well as geographical and climate conditions prevailing in the location under consideration. For over five decades, data gathered by the United States Environmental Protection Agency (US-EPA) [34] shows that paper and paperboard make up about twenty-five percent of the total MSW generated for a period spanning from 1960 to 2018. Figure 2 shows estimated values for the composition of MSW generated in the USA in 2018 alone. Clearly, it can be observed that paper and paperboard account for almost a quarter of the total of 292.4 million tonnes of MSW that was generated in the USA in 2018.

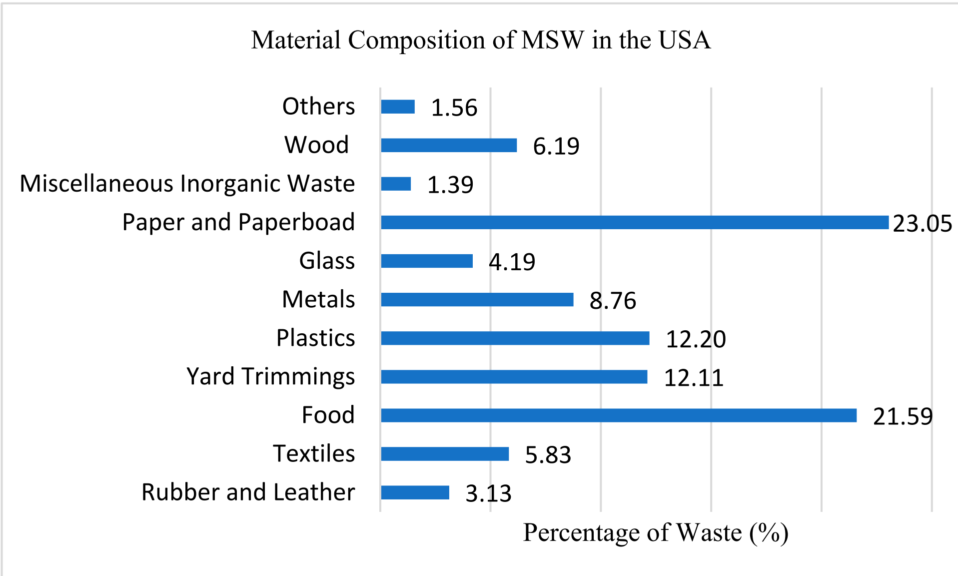

Figure 2. Material composition of MSW in the USA for 2018 [34].

The waste composition in Ghana, just like how it is done in other parts of the world, can also be segregated into various compositions. A study [35] indicates the composition of the MSW in Ghana as follows:

- Organics—which consist of food waste, wood, yard waste, and animal droppings;
- Paper—cardboards, newsprints, tissue, and office papers;
- Plastics—polyethylene terephthalate (PET), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polystyrene (PS), polypropylene (PP), and other plastics;
- Metals—scrap and cans/tins;
- Glass—both coloured and plain ones;
- Leather and rubber;
- Textiles;
- Inert (fine organics, ash, and sand);
- Miscellaneous (paints, demolition and construction waste, batteries, any other fraction that does not fall into the above categories).

The study concluded that the composition of MSW generated in Ghana is dominated by the organic component (constituting 61%), followed by plastics (constituting 14%), and the rest are 5% paper, 3% metal, 3% glass, 1% rubber and leather, 2% textiles, 6% inert, and 5% miscellaneous; this is depicted in Figure 3.

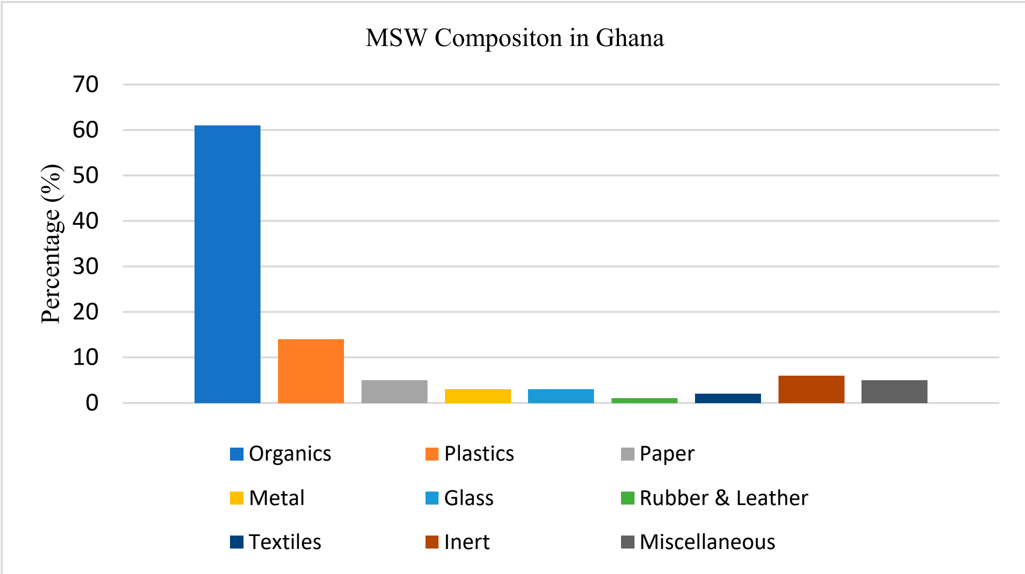

Figure 3. MSW composition in Ghana [35].

Sources of MSW may differ from one area to another depending on the category of waste and the definition for the scope of waste that the municipal authorities oversee. However, a study [25] identified six main sources of MSW. These sources are as follows:

- Residential—The report identified single and multifamily dwellings as typical waste generators and identified food waste, e-waste, paper, plastics, household hazardous waste, leather, glass, etc.
- Commercial—Another source of MSW identified by the report is the solid waste from commercial sources. Under this category, markets, stores, hotels, restaurants, and office buildings are typical waste generators. Some of the types of solid waste identified include paper, cardboard, food waste, e-waste, etc.
- Institutional—Schools, government buildings, airports, prisons, and hospitals (non-medical wastes) were identified as typical waste generators. The same types of solid waste listed under commercial sources were also identified for institutional sources.
- Industrial—Typical waste generators under this source of MSW include construction sites, fabrication, chemical plants, light and heavy manufacturing, and power plants. Some types of solid waste given under this section include hazardous wastes, packaging, food wastes, housekeeping wastes, etc.
- Construction and demolition—Solid waste from construction and demolition sources including that from new building sites, road maintenance, renovation sites, and the pulling down of buildings are identified as typical construction and demolition waste generators. Some types of solid waste under this section include bricks, tiles, wood, steel, concrete, and dirt.
- Municipal services—Under this category of MSW source, street cleaning, landscaping, recreational zones, water, and effluent treatment plants were identified as typical waste generators, while landscape and tree trimmings, street sweepings, general waste from recreational areas, and sludge were identified as other types of solid waste.

Commercial, institutional, and industrial sources are oftentimes grouped and constitute more than 50% of MSW. However, if the municipal authorities oversee the collection and disposal of the following types of waste, then they can also be classified as a source of MSW [25]:

- Process—Refineries, power plants, chemical plants, processing and mineral extraction, and processing constitute some typical waste generators, while materials such as slag, tailings, industrial process waste, and scrap materials are some examples of typical processed solid waste.

- Medical waste—Under this category of MSW source, hospitals, nursing homes, and clinics were identified as typical waste generators, while pharmaceutical waste, infectious waste such as hand gloves, bandages, cultures, and hazardous waste, i.e., chemicals and sharp objects, were identified as typical solid waste.
- Agricultural—Typical waste generators identified under this category include crops, dairies, orchards, feedlots, and farms, while spoiled food waste and hazardous waste such as pesticides were identified as typical agricultural solid waste.

As a part of programmes to combat waste, many countries have developed strategies to mitigate against escalating rates of MSW generation. In some literature, the disposal and management of waste is usually presented as integrated waste management (IWM), and according to Tchobanoglous G. et al. [26], IWM is defined as "the selection and application of suitable techniques, technologies, and management programmes to achieve specific waste management objectives and goals". There are basically four IWM strategies that are adopted by the United States Environmental Protection Agency [36].

Source reduction: This strategy of MSW management is focused on reducing either the volume or harmfulness of the waste generated and can be adopted by all and sundry. A more pragmatic approach to this strategy of waste management is to switch to reusing products and packaging (a typical example of such is the use of returnable bottles). Consumers are usually encouraged to partake in source reduction through buying as few products as possible or through using products expeditiously [26]. According to a study [37], while low-income countries have no structured programmes for source reduction, the situation, nevertheless, is different from high-income countries, where a great deal of educational programmes are organized which emphasize the necessity to reuse, reduce, and recycle waste (what has been nicknamed the three Rs of waste). A study [38] described source reduction as an immediate aid to the current environmental crisis. The study also stated that not only does source reduction addresses the core issues of waste problems but also takes into consideration the likelihood of environmental consequences as a result of population growth, with accompanying consumption and scarce resources that cannot satisfy the needs of mankind. Additionally, Tchobanoglous G. et al. [26] considered source reduction as the best practice at the process design phase of the production of any product. Johnson B. [38] listed three practices that can be implemented to reduce waste. These are listed below:

- Evaluate past consumption—This can be achieved through assessing the true use and need of everything, after which ones which are deemed unnecessary are pared down.
- To limit present and future consumption in terms of amount and size—This can be achieved through minimising shopping activities to conserve valuable resources which are used to make new things and through making used items available to others. Areas that can be considered include home sizes, reducing packaging, personal effects, etc.
- Decreasing activities that may support or lead to consumption.

Source reduction is usually seen as the best approach and is encouraged via making sure the cost of the management of waste is fully internalized. The costs that need to be internalized, for waste management, include the site, administrative, pickup and transport, construction, salary, and environmental monitoring controls [26]. Although source reduction is perceived to be an effective way of managing waste through making sure that the amount of waste generated is minimal, that cannot stop the generation of waste in society. There is, therefore, a need to pursue other means of disposing and managing the waste that would eventually be generated.

Recycling and composting: Among waste management practices, recycling is considered perhaps the most positively perceived and achievable strategy. Recycling returns a substantial amount of raw materials to the market through separating reusable products from the remainder of the municipal waste stream, thus saving limited resources to feed the industry. A study indicates that recycling can improve the ash quality of incinerators and composting facilities, as well as improve the facilities' efficiency by means of removing non-combustible materials, such as glass and metals [26]. Recycling is applicable only in the disposal and management of only the inorganic component of waste. The biological decomposition of organic waste (such as food and plant materials) by either worm, fungi, bacteria, or other organisms, usually under controlled aerobic conditions, is referred to as composting. This method of waste management can be used in the treatment of only the organic component of MSW.

Landfills: The cheapest and most widely used means of waste disposal worldwide, and mostly in developing countries, has been the landfill [39]. However, this traditional means of waste disposal has been a major environmental problem that pollutes the air, land, groundwater and endangers human health [40]. Landfill has also been found to be a major culprit to greenhouse gases. It has been estimated that landfill contributes about 5% of the greenhouse gases (methane (CH_4), nitrogen oxide (N_2O), carbon dioxide (CO_2)) that deplete the ozone layer as well as cause climate change [41]. Leachate from waste dumps contains huge amounts of dissolved fatty acids, methane, nitrate, calcium, phosphates, chloride, sodium, potassium, magnesium, and trace metals. The leachate from the waste dump in landfill sites is attributed to be a major cause of severe pollution in aquifers and causes serious eutrophication conditions, predominantly in surface water [42].

WtE technologies: There are a plethora of definitions that are given for WtE technology, and this can be very broad, since it encompasses those that are simple and others that are complex in design. Basically, WtE technologies are defined as all technologies that treat waste with the aim of energy recovery at the end of the process. The recovered energy from any WtE technology can be either electricity, heat, or fuels (in solid, liquid, or gaseous form).

In Ghana, it is estimated that MSW constitutes about 80% of the total amount of waste generated in the country [22]. It is also estimated that over 90% of the total waste generated in developing countries is disposed of inappropriately; it is either burned in the open or dumped in uncontrolled landfill sites [43]. The indiscriminate dumping of waste onto the streets, gutters, and rivers which is left uncollected is attributed to causing flooding and the spread of diseases. A study [35] estimates that the per capita waste generation per day in Ghana is 0.47 kg/person/day, which translates into over 14,000 tonnes of solid waste generation per day. Another study [44] estimates that out of the total waste generated in the six main municipalities in Ghana, only 28% is collected, and the rest disposed of as mentioned earlier. The collection of solid waste in Ghana has, however, seen an improvement in recent years, with the participation of private individuals and companies. The activities of these private individuals and companies include the collection of waste from various households, institutions, and commercial places and dumping the collected waste into open landfill sites, mostly in the outskirts of the town, while others dump them into unauthorized places (including rivers and streams) [45]. There is, therefore, a need to pursue sustainable programmes that can help in the management of MSW generated in the country.

2.2. WtE Technologies

WtE technologies can broadly be classified into two types, namely, thermochemical and biological conversion methods. Figure 4 is a flowchart of the various methods of WtE technologies including the useful energy that can be derived from each technology.

2.2.1. Thermochemical Conversion Methods

The thermal conversion method of waste-to-energy technology is the application of heat and/or air (or oxygen) in treating MSW to generate electricity and heat. Thermal conversion methods of the WtE technology process can be either exothermic or endothermic. Thermochemical conversion methods, relative to biological conversion methods, have been estimated to be more efficient due to their faster reaction rates and larger reduction in the mass and volumes of the MSW [46]. The thermal conversion method of WtE technology can be divided into waste combustion (also referred to as waste incineration), gasification, and pyrolysis. The distinction between the various types of thermal conversion WtE technology depends on the degree of temperature and the amount of air (or oxygen) concentration.

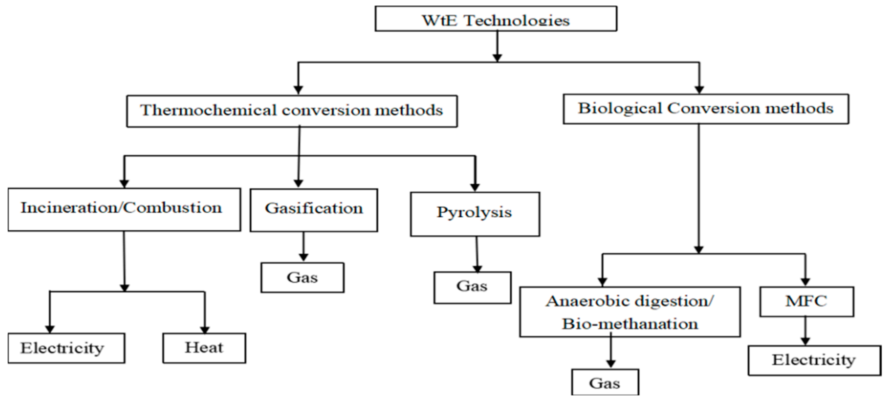

Figure 4. A flowchart of the various WtE technologies and their end products [10].

Waste incineration/combustion is a type of WtE technology where, usually, mixed MSW is burned in the presence of excess air or oxygen at temperatures between 800 °C and 1200 °C. Unlike earlier waste incineration facilities which had the sole aim of reducing the mass and volume of MSW that will be sent to landfill sites, recent waste incineration facilities have systems incorporated for the production of steam and, subsequently, for electricity generation. Waste incineration facilities with energy recovery are, in principle, similar to a power plant that is fired by fossil fuels. A typical waste incineration facility with energy recovery consists basically of a waste storage, a boiler or incinerator, a steam turbine, and a flue gas treatment system.

Gasification is a partial oxidation process through which carbonaceous materials (e.g., MSW) are converted into a gaseous form referred to as a synthetic gas (syngas). Most of the carbon and hydrogen in the waste are converted into syngas comprising mainly carbon monoxide (CO), CH_4, and hydrogen (H_2), leaving behind a solid residue of inert ash and char. In gasification, an external heat source is needed to maintain its operating temperatures at optimum levels. The process of gasification is largely exothermic, although some amount of heat may be required to initiate the process and sustain it. The processed syngas can be used for a variety of applications (after cleaning). The syngas derived from the process of gasification is usually combusted in internal combustion engines to produce heat and electricity. The syngas produced during gasification may also be used to manufacture high-quality oils, additives, or synthetic natural gas (SNG) after it has been treated [47].

Pyrolysis is the thermal decomposition of carbon-based materials at higher temperatures in the absence of oxygen. This process involves the change of the chemical composition of the feedstock (MSW in this case). The pyrolysis of organic compounds produces volatile materials referred to as synthetic gas (syngas), a carbon-rich solid residue known in general as bio-char, and an oil also known as bio-oil [48]. The amounts of valuable products from the pyrolysis process (CO, H_2, CH_4, and other hydrocarbons) and their proportion depend exclusively on the pyrolysis temperature and the rate of heating. Bio-char is usually produced at temperatures below 450 °C, while syngas is produced at temperatures above 800 °C; however, bio-oil is produced at relatively intermediate temperatures. In the processes of combustion and gasification, pyrolysis is considered as the first step [48]. An external heat source is required to maintain the temperature throughout the process of pyrolysis, and as such, pyrolysis is an entirely endothermic process. A study estimated the net calorific value of syngas produced during the process of pyrolysis to be between 13 and 20 MJ/Nm^3 [49]. The produced syngas can be combusted in internal combustion engines for the generation of heat and electricity. However, the syngas is cleaned prior to being combusted in the internal combustion engines. It has also been reported that the pyrolysis of plastic materials can produce liquid hydrocarbons, which can be distilled such that they have properties similar to petroleum-based fuels (e.g., diesel and petrol) [49]. Advantages of pyrolysis relative to incineration and gasification include the production of multiple valuable products (which can either be solid, liquid, or gas). Additionally, pyrolysis has the least economic concern as well as minimal environmental effects [50,51]. The major setback of this technology, however, is that to achieve optimum results, solid waste must be segregated, and suitable components must be shredded prior to pyrolysis [50]. Additionally, pyrolysis cannot be used in the management of all solid waste.

2.2.2. Biological Conversion Methods

The biological conversion methods of WtE technology use micro-organisms in carefully controlled conditions to convert MSW into biogas, consisting mainly of methane and carbon dioxide and a stabilised residue known as digestate. Anaerobic digestion/bio-methanation and microbial fuel cells (MFCs) are all biological conversion methods of WtE technology.

Anaerobic digestion (AD): AD is a mechanism in which organic matter is broken down by microorganisms in the absence of oxygen, resulting in biogas, a methane-rich gas used as a fuel, and digestate, which is a nutrient-rich fertiliser. The operating time per cycle, or how long it takes for an anaerobic digestion plant to process organic waste, is usually 15 to 30 days [52]. With a combined heat and power unit, the biogas, generated naturally in sealed tanks, is used to generate renewable energy in the form of electricity or heat. The bio-fertiliser is pasteurised, which can eliminate pathogens and can be applied twice a year to farmland, effectively replacing fossil-fuel-based fertilisers. This technology is commonly used in the treatment of wastewater but can also be employed in the treatment of organic waste ranging from household and industrial food wastes to manures and biofuel crops. The steps involved in the anaerobic digestion process are hydrolysis (where hydrolytic enzymes break down complex polymers into basic amino acids, sugars, and fatty acids), acidogenesis (breakdown of simple monomers into volatile fatty acids), acetogenesis (products of acidogenesis are broken down into acetic acid), and finally, methanogenesis (methane and carbon dioxide are produced) [53]. These steps usually take place in reactors which are enclosed systems (referred to as digesters). Elango D. et al. [54] estimates that 100 m^3 of biogas can be generated from a tonne of MSW.

Microbial fuel cell (MFC): The MFC is a system that utilises micro-organisms to transform chemical energy into electrical energy [55]. A bio-cathode and/or a bio-anode are used to create these electrochemical cells, and a membrane divides the anode (where oxidation takes place) and the cathode compartments in most MFCs (where reduction takes place). In MFCs, the electrons which are produced during oxidation are directly transferred to an electrode or a redox mediator species. The electron flux is transferred from the anode to the cathode. Most MFCs oxidize an organic electron donor to produce CO_2, protons, and electrons. Other electron donors, such as hydrogen or sulphur compounds, have been identified [55]. The cathode reaction employs several electron acceptors, the most common of which is oxygen (O_2). It can be applied in power generation, biosensors, and wastewater treatment.

Waste incineration with energy recovery is reported to be the most matured WtE technologies employed worldwide [9]. Waste incineration with energy recovery is reported to be the most successful WtE technology employed in the EU, with Germany, France, Italy, France, the United Kingdom, and Sweden having the biggest investment in this technology [56]. A study indicates that in 2017 alone, a total of about 96 million tonnes of solid waste were combusted in the over 492 WtE plants [57] operating in the EU. Sweden is considered one of the most successful countries worldwide in terms of disposing and managing its MSW using waste incineration with energy recover. It is estimated that there are about 34 waste incineration facilities in Sweden which generates electricity to power about 250 000 homes [57,58]. It is also estimated that Sweden has been able to reduce the amount of solid waste that is sent to landfills to about 0.5%, where over 50% of the MSW generated in various households in 2017 were treated at the various waste incineration facilities operating in the country [57]. Another study also indicates that in 2017, the capacities of the waste incineration facilities operating in Sweden were higher than the amount of combustible MSW generated in the country [59]. Additionally, in the EU, it is also reported that Germany leads in the use of the waste incineration technology with regard to the electricity generation capacity from waste incineration (with a generation capacity of 1925 MW), followed by the UK and Sweden with electricity generation capacities of 925 MW and 876 MW, respectively [60].

Tan et al. [12] estimates that Japan has the highest number of waste incineration facilities in operation worldwide, with about 1900 waste incineration facilities operating in the country. These waste incineration facilities are used in the disposal and management of over 80% of the MSW generated in the country. The total power generation capacity of the various waste incineration plants in Japan is estimated to be 10,153 GWh [61].

In the USA, it is reported that there are currently about 77 waste incineration facilities that are operating in about 25 states. These waste incineration facilities burn about 7% of the total amount of MSW generated all over the USA (which is equal to about 90,000 tons per day). The base load of these waste incineration facilities electrical generation capacity in the USA is estimated to be equivalent to 2700 MW, which is able to meet the power demand of more than 2 million homes in the USA [10]. The use of waste incineration facilities in the disposal and management of MSW in the USA, however, has not been a widespread approach relative to the EU and Japan. This has been attributed to a number of factors, and these factors according to the US-EPA [34] include the following: (1) the vast availability of land in the USA means the construction of new landfilling sites has never been problematic. This, therefore, presents the availability of a cheaper option for the disposal and management of MSW in the short term, which is landfilling. (2) There is public opposition to the construction of new waste incineration facilities in many states in the USA. This is because early waste incineration facilities in the USA did not have air pollution controls; therefore, waste incineration facilities have gained notoriety as a high-pollution technology.

In order to minimize the use of land for landfilling in China, a number of guidelines were introduced, and these guidelines encouraged the use of various WtE facilities, including waste incineration, in the disposal and management of MSW in China [62,63]. Studies [64,65] estimate that in 2019, a total of about 121.7 million tonnes of waste were combusted in various waste incineration facilities in China, generating a total of about 60.7 billion kWh of electricity, which makes China the biggest marketplace with regard to installed capacity and electricity generation for WtE technology worldwide. The use of waste incineration is reported to be also gaining popularity in most inhabited developing countries such as Brazil, Indonesia, Pakistan, Bangladesh, and Nigeria, where huge volumes of MSW are generated, and which incidentally have high energy needs [66–68].

In Ghana, a study [22] reported that there are about 12 controlled waste incinerators without energy recovery and about 232 uncontrolled waste incineration sites that are scattered all over the country. The study also reported that a waste incineration facility was to be commissioned in Kumasi and was expected to generate about 30 to 52 MWh of electricity from 1000 tons of MSW. However, no further information on the current operation condition, location, and the current state of this reported waste incineration plant was found both on the proposed site and in the literature. It is also reported that a WtE plant was expected to be commissioned in the Atwima Nwabiagya district of the Ashanti region of Ghana. This WtE plant, which is reported to be the first of its kind in the country, is a hybrid PV-biogas pyrolysis plant. This plant is expected to generate about 200 kW of solar power, 100 kW of biogas, and an additional 100 kW from the pyrolysis of plastic waste [56,69].

3. Discussions

The decision to select an optimum technology for use in a particular location can be complex, since a lot of factors need to be considered. In the evaluation of the optimum WtE technology that can be adopted for use in a particular location, a lot of researchers have proposed several factors that are worth considering. Although the cost of the technology is very important if it is to be adopted, that should not be the determining factor. A study [10] highlighted three main points that can be considered cardinal in selecting a WtE technology for a location of interest.

The state of the technology to be adopted is an initial and crucial criterion to consider. This includes (1) considering the degree to which this technology has been proven on a commercial scale, as it must be noted that some of these technologies may only have been proven in pilot or in laboratory operations; (2) the operation history of the technology; (3) the freedom of the technology from high failure modes; and (4) the demonstrated reliability of the entire system.

The second criterion that is worth considering is the technical performance of the WtE technology. The technical performance of the technology that needs to be assessed includes (1) a consideration of the compatibility of the technology with the full spectrum of the waste system at the location of implementation of the technology, (2) the ability of the implemented technology to produce marketable by-products from the technology, and (3) the need for pre-processing of the MSW at the location of the technology (if any). Last but not least, the final criterion worth considering is the availability of technical resources for the technology to be adopted. This criterion includes (1) proven contractor experience for the technology at the location, (2) the proximity of technical support for the WtE technology, and (3) the availability of support on a continuous basis.

4. Conclusions

It is evident from the literature that the disposal and management of MSW is really challenging in nations worldwide. However, the use of waste incineration has proven to be an attractive WtE technology in the disposal and management of the voluminous amounts of MSW generated worldwide. It is also evident from the literature that waste incineration is the WtE technology which is most widely employed in developed nations and is gradually gaining recognition in some developing nations as well for the disposal and management of MSW.

Thermochemical conversion methods like gasification and pyrolysis have shown to have great potential. However, there are a few gasification and pyrolysis facilities operating worldwide. A study [10] indicates that there are at least two gasification plants powered by MSW in operation in Japan and a few other relatively smaller gasification plants which are in operation in Europe and Asia. Additionally, gasification and pyrolysis reactors fired by MSW are not relatively mature WtE technologies, with most of them being at either the pilot stage or under research.

Waste incineration with energy recovery is the only WtE technology which has been proven commercially for over five decades, with over 2000 plants in operation worldwide. It has a mature industry which has been addressing high risks and is current with design codes and operational procedures [70]. It is the only technology with a plant availability of between 92 to 96% and many plants with life spans which exceed 20 to 30 years [10]. Waste incineration can be used in the management of all compositions of MSW streams including treated lumber, a limited percentage of tyres, and mercury-containing devices. There is availability of a market for by-products from waste incineration like electricity (waste incineration facilities can generate over 600 kWh of electricity per tonne of waste), steam, hot water, ferrous and non-ferrous metals, and aggregates which can be used as landfill cover. Waste incineration has fewer environmental effects relative to landfills [71]. In waste incineration facilities, there may be no need for the pre-processing of MSW [72], apart from the removal of bulky items of delivered waste (which mostly may constitute an insignificant percent of the MSW) [10].

Waste incineration with energy technology is a WtE technology which relies on waste generation in society as its feedstock (i.e., MSW), which is burnt in the combustion chambers of these facilities, and at the end, useful energy is recovered. This means waste generation in society has become a source of power generation in waste incineration plants [73]. This can improve the disposal and management of MSW in developing countries including

Ghana while contributing to the energy security of the country and, additionally, reducing CO_2 emissions from the conventional power plants operating in the country.

It is recommended that a techno-economic assessment of a waste incineration facility is performed on a proposed plant for use in Ghana. Also, in recent times, the application of artificial intelligence in most sectors is being studied. In this regard, there are studies [74,75] which have explored the use of artificial intelligence in the management of MSW. It is therefore recommended that the possibility of incorporating artificial intelligence into the management of MSW in developing countries including Ghana is investigated.

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