Investigation into Energy Generation from Solid Waste Management in Selected Areas of Western States of Nigeria

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Abstract

This research describes the current situation of waste management in Nigeria, highlighting the challenges and opportunities for energy generation and improved energy efficiency via waste-to-energy technologies using waste as feedstock. For a suitable and sustainable energy generation, various energy conversion technologies were observed. Thereafter, the attached benefits of the various technologies in terms of economic, environmental, and energy are contained in this report. In addition, this study identified what constitutes solid waste, and sources of generation, developed appropriate sorting method for separating the solid waste into its components. The energy convertible ones were identified as well as calorific value available in each component. This we believe will help those seeking energy from solid waste to make decisions. The technologies behind each conversion method were also explained in this study as well as the cost implication. This investigation proved that: anaerobic digestion is a net energy-producing process; biogas facilities produced high-quality renewable fuel; surplus energy as electricity and heat is produced during anaerobic digestion of biomass; anaerobic digestion reduces reliance on energy imports; the facilities involved positively contributed to decentralization and distribution of power system and it proved also that biogas is a rich sources of electricity, heat and transportation fuel. In no doubt, this research will assist small, medium and large scale industries in both developed and developing countries to made decision when sourcing for energy to man their industries. It will also go a long way as help for domestic use.

Key words: energy generation, investigation, opportunities and challenges, municipal solid waste (MSW), waste management.

Introduction

Waste is generally defined as any material that is no longer needed or no longer useful to the owner. Wastes can be solid, liquid or gaseous. However, the focus of this research tends to be on solid wastes. Solid wastes typically may be classified as follows: Garbage; decomposable wastes from food. Rubbish; non-decomposable wastes, either combustible (such as paper, wood, and cloth) or non-combustible (such as metal, glass, and ceramics). Ashes: residues of the combustion of solid fuels (Daskalopoulos, 1998, Basic Facts, 2005). The history of garbage is as old as human kind itself. For most of the past two and a half million years, human beings have left their garbage where it fell (Williams et. al., 1993). Dumping waste on the outskirts of town or into natural depressions or valleys has long been the favoured practice, because it was cheap and healthy, and environmental issues were not a priority (Glover, 1995).

Wastes sources can be domestic, industrial, agricultural, commercial or institutional. The wastes generated from these sources can be biodegradable-able to decompose naturally or non-biodegradable-those that cannot decay or decompose naturally. In the developing countries like Nigeria, wastes have been found to have high organic content and are biodegradable. Osewa, (1993) gave the composition of Nigeria city wastes as in Table 1 (Cointreau, 1982; USEPA, 2003). In developing countries, there is a much higher proportion of organics, and considerably less plastics (Cointreau, 1982).

Table 1. Solid Wastes Generated in Urban Cities

Component	Composition (% by weight)
Paper	1-10
Glass, Ceramic	1-10
Metals	1-5
Plastics	1-5
Leather, Rubber, Wood, Bones	1-5
Wood, Bones Straw	1-5
Textiles	1-5
Vegetable, Putrescible	40-85

Source: (Osewa, 1993**)**

Table 2 shows the composition of municipal solid wastes (MSW) with high organic matter in Nigeria.

Table 2. Composition of Municipal Solid Wastes in Nigeria

Waste Source	**Waste Category (%)**							
	Putrescibles	Plastics	Paper	Metals	Glass	Textiles	Fines	Others
Low Density	57.5	6.10	4.30	2.50	2.30	2.90	21.0	3.40
Medium Density	53.7	7.10	4.10	2.01	1.70	2.40	27.1	1.70
High Density	36.4	8.04	2.59	1.75	0.86	3.67	41.0	5.73
Commercial	27.9	10.20	10.90	3.40	6.90	1.20	36.4	3.10
Institutional	44.80	5.90	8.90	0.90	1.20	0.30	36.4	3.10

Source: (Sha'Ato et al, 2007)

Solid Waste Management

Waste management is the collection, transport, processing, recycling or disposal, and monitoring of waste materials. The term usually relates to materials produced by human activity, and is generally undertaken to reduce their effect on health, the environment or aesthetics. Waste management is also carried out to recover resources from it. It involves solid, liquid, gaseous or radioactive substances, with different methods and fields of expertise for each.

Solid Waste management practices differ for developed and developing nations, for urban and rural areas, and for residential and industrial producers. Management for non-hazardous residential and institutional waste in metropolitan areas is usually the responsibility of local government authorities. Meanwhile, management for non-hazardous commercial and industrial waste is usually the responsibility of the generator (Agunwamba, 1998; Daskalopoulos, 1998). Onibokun and Kumuyi (2003). These wastes are illegally disposed of on to any available space, known as Open-dumps as shown in Fig. 1.

Fig. 1. Abule Egba Dumpsites. Source: (LAWMA, 2008)

The Federal Environment Protection Agency (FEPA) was established in 1988 to control the growing problems of waste management and pollution in Nigeria (Onibokun and Kumuyi, 2003; Bankole, 2004; Onibokun and Kumuyi (2003). In Ibadan in 1991, there were twenty-three registered private waste collectors, but only ten were found to be operational (Onibokun, 1999). Over forty trips are made per day from the city to the dump site in Lagos, only two trips are possible each day (UNESCO, 2003).

The average household waste generation rate in Nigeria is 0.55 – 0.58 kg per capita Solid Waste Audit Report, (2004). Many waste management methods have been practiced, perhaps from the beginning of human existence on earth.

We sweep and take it to the back of the house, and when it becomes large, we burn it (Sha'Ato et al, 2007). They use various conversion technologies such as decomposting and thermal treatment (USEPA, 2003).

Forms of most common Solid Waste Management were fully discussed and well explained to be four methods which are: landfilling, incineration, composting and anaerobic digestion. Incineration, composting and anaerobic digestion are volume reducing technologies; ultimately, residues from these methods must be landfilled (Seo et al, 2004, Daskalopoulous, 1998 and El-Fadel, 1997). Sample of overflowing landfill is shown in Fig. 2.

Fig. 2. An Overflowing Landfill. Source: (USEPA, 2003)

Leachate forms as water percolates intermittently through the refuse pile, and can contain high levels of nutrients (nitrogen, phosphorous, potassium), heavy metals, toxins such as cyanide, and dissolved organics (El-Fadel, 1997). Benefits of incineration include reduction of volume of waste and production of energy in the form of electricity and heat

(Seo et al, 2004). However, construction and start-up costs of incineration facilities can be prohibitively expensive for developing nations.

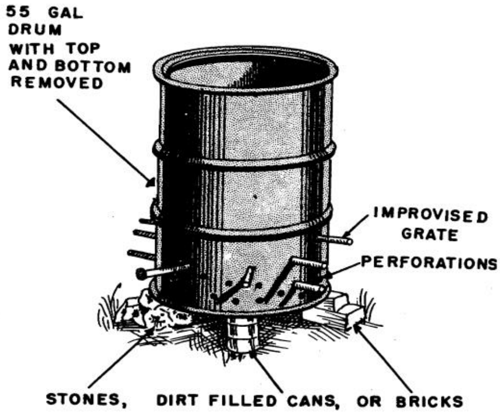

Fig. 3. A Barrel Incinerator Source: (USEPA, 2003)

Some other areas of research work that were reviewed are: Composting and anaerobic digestion (Sonesson, 2002), Health and Environmental Impacts of Municipal Solid Waste (Hester et al., 2002; Seo et al, 2004), Landfills: (Neal and Schubel, 1987), Incineration (Garrod and Willis, 1998; Daskalopoulos, (1998,) and Neal and Schubel, (1987)**.** Composting/Anaerobic Digestion, Garrod and Willis, (1998) and (Swan, 2002).

Other risks: Workers commonly experience itching eyes, sore throats, and respiratory diseases (Gladding, 2002 and Techobanoglus, 1993). Environmentally speaking, recycling uses a large amount of energy resources (Daskalopoulos, 1998).

Municipal Solid Waste Collection

The method and frequency of refuse collection depend upon a number of factors such as the size of the installation, the type of equipment available, the availability of civilian contractors, the market for salvageable materials, and the climate. There are many types of collection vehicles available; however, collection vehicles fall into two basic types: waste-haul and container-haul.

A waste collection vehicle is more generally known as garbage truck and dustbin lorry. These trucks are used for picking up waste and then moving it to landfills or other places where waste materials are managed and treated. For waste collection vehicles, we have five kinds and they are:

Front Loaders. This shown in Fig. 4. As soon as the container receives, the garbage it gets it compacted with the help of a Packer blade. This blade has the content of the container pushed toward its rear.

Fig. 4. Front-loading compactor vehicle emptying a self-loading container. Source: (USEPA, 2003)

Rear Loaders. This is seen in Fig. 5. Rear loader is a sort of truck which quit often compresses the waste. This compression is done with help of system, which is recognized as sweep-and-slide. The waste is compressed while it is pushed against the front wall of the loader.

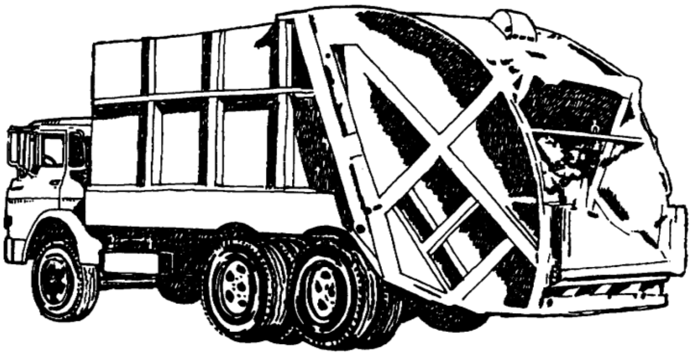

Fig. 5. Typical rear-loading compactor vehicle. Source: (USEPA, 2003)

Automated Side Loaders (ASL). As seen in Fig. 6, it is used to pick up only mobile garbage bins. It is capable for picking up bins ranging from 80 to 240 liters capacity however. Additionally, automated side loaders only require a single person for their operation while other loader lack this capacity and require two to three persons for operation.

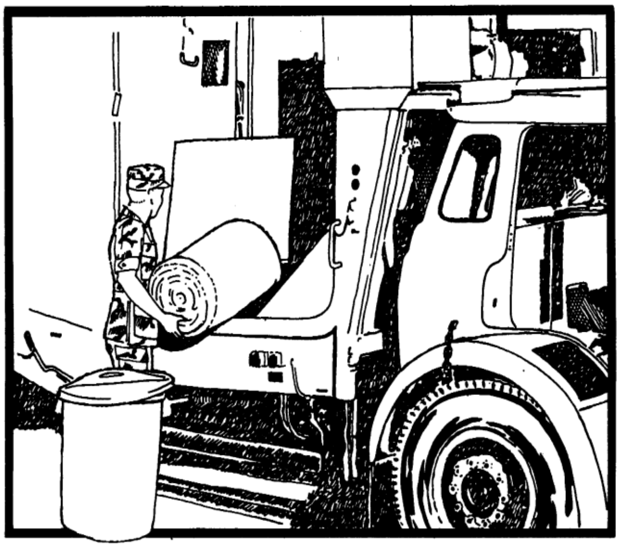

Fig. 6. Side-loading compactor vehicle. Source: (USEPA, 2003)

Pneumatic Collection Vehicles. These loaders have a crane built in with them assisted with mouthpiece for fitting in a hole you can find concealed under a plate on the street. Some exceptional loader can even pick up 360 liters. This system helps the operator to have the waste collected even at the times when access is blocked under hurdles. This is seen in Fig. 7.

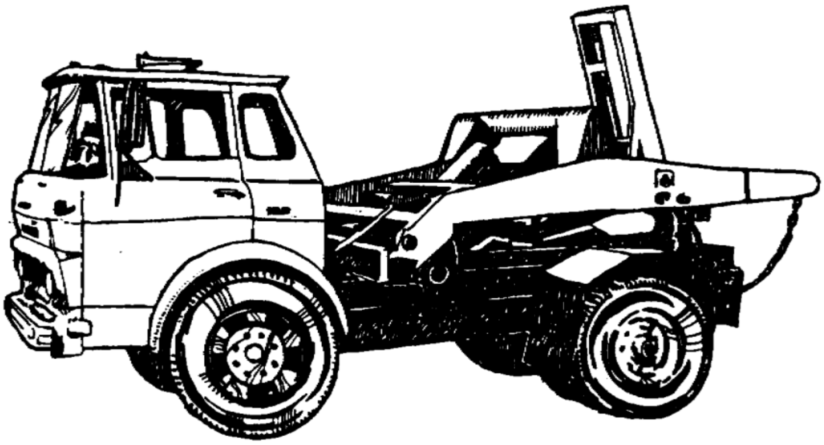

Fig. 7. Hoist-and-haul vehicle without container. Source: (USEPA, 2003)

Grapple Trucks. This truck makes the operator to collect a volume of waste. Therefore, to have them collected they have formed grapple trucks this is as shown in Fig. 8.

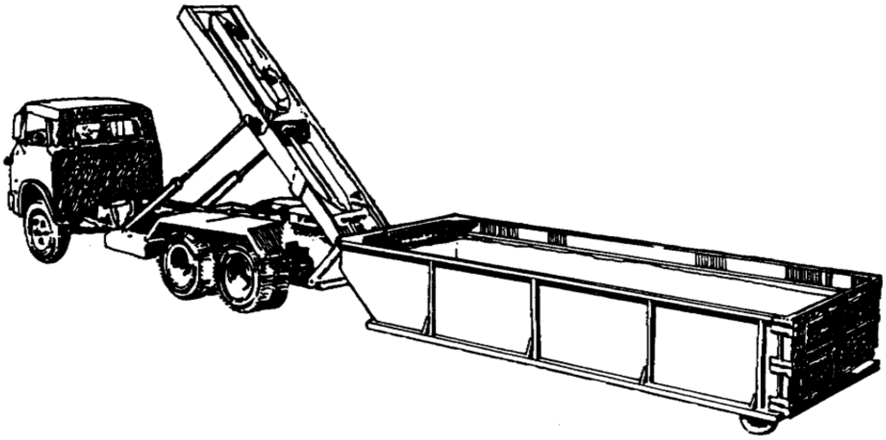

Fig. 8. Loading a roll-off container on to a tilt-frame truck Source: (USEPA, 2003)

Processes of Waste Minimization

The policy and process to have the waste minimization means to reduce the production of waste at society and individual level. The followings are means of waste reduction or minimization process: Optimization of Resources, Using again the scrap material, Quality control improvement and process monitoring, Exchanging Waste, Point of use from ship, and Durability.

The need to prevent wastes from constituting a nuisance and health hazards to humans and the environment necessitates this research. This enables wastes to be properly managed and converted into useful energy sources for industrial and domestic uses. The study serves as a means of meeting the energy needs of the country through renewable energy development. This helps in boosting the commercial activities and also reducing the risks of epidemic and diseases that had associated with improper solid waste management in the country

Hence this research : identify what constitute solid waste and its generation sources; develop appropriate sorting method for its separation to different components; develop and encourage an effective and efficient method of converting wastes to energy to solve the energy problem of the nation; create a means of income generation through waste to wealth technology across the country, and to provide employment opportunity and improve the health condition of the populace by removing many environmental and health risks and hazards associated with open dumping and improper waste disposal systems.

This research determined the various methods of solid waste management in the rural and urban areas in Nigeria. It also involves the determination of various forms of energy that can be derived from efficient and effective solid waste management. The cost effectiveness of the method to be used, and the environmental impact assessment was determined.

Methods

The research methodology reviewed the existing methods, means, and technologies being used in the developed countries, such as the United State, England, Germany, to convert solid waste into energy generation. This is due to the facts that there is no any visible, notable and recognized waste derived energy program in the country. The scope of the method covers analysis, feasibility, efficiency, and cost effectiveness of these technologies as being practiced in the developed countries, and how it can be applied to Nigeria situation.

Energy Situation in Nigeria

The problem facing Nigeria is that of socio-economic development. The socio-economic indices such as industrial and agricultural production and infrastructural facilities depend directly on energy supply. Nigeria is listed among the poor nations of the world. This rating is directly related to the energy consumption per capital in Table 3.

Table 3. Energy Consumption per Capital

S/N	Country	Kwh/Capital
1	U.S.A	12,711
2	Senegal	95
3	Cote d'Ivoire	139
4	Ghana	346
5	Nigeria	168

Source: (BTRC, 2005)

Nigeria is over dependent on conventional energy sources such as crude oil, National gas, Coal and Lignite, Tar sands and Hydropower. The non-conventional energy sources that has been neglected has been found to be a great energy resource alternative. Table 4 shows the non-conventional energy source.

Table 4. Nigeria Non-Conventional Energy Resources

Resource		Reserve
1.	Fuel wood	43.3 million tones/year
2.	Animal waste and Residue Crop	144 million tones/year
3.	Small scale Hydro power	734.2 MN
4.	Solar radiation	1.0 Kw per m^2
5.	Wind	2.0 – 4.0 m/s

Source: (Esan, 2001)

From Table 4, it shows that Annual waste and crop residue is a great energy resource for Nigeria. The advantage of waste-to-energy technology is that it is a renewable energy source unlike crude oil that is non-renewable.

Existing Biomass Technology in Nigeria

The Biomass technology has not been properly developed in Nigeria, but some efforts have been achieved to domesticate the technology in order to meet the energy demand of the country. A number of indigenous outfits are producing economically viable systems for converting municipal waste to energy. Table 5 shows the estimated biomass resources in Nigeria.

Table 5. Biomass Resources and the Estimated Quantities in Nigeria

Resource	**Quantity (million tonnes)**	**Energy value ('000MJ)**
Fuel wood	39.1	531.0
Agro-waste	11.244	147.7
Saw Dust	1.8	31.433
Municipal Solid waste	4.075	-

Source: (Oyedepo, 2012)

Waste-to-Energy Generation

This involves converting various elements of municipal solid waste such as paper, plastics, and woods to generate energy by either thermo-chemical or biochemical processes. Fig. 9 shows many potential output energy technologies and the products that result from those processes.

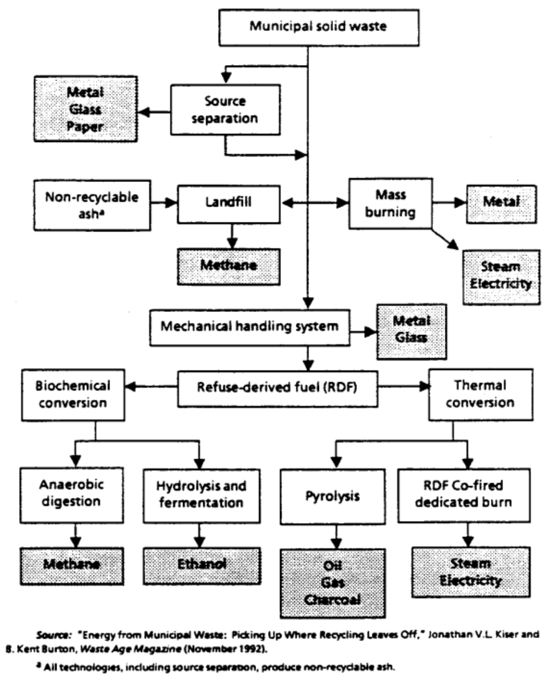

Fig. 9. Energy from Municipal Waste. Source: (Jonathan, 1992; Rathje,1991)

Waste-to-Energy Technology

Waste-to-energy technologies are used to convert waste matter into various forms of fuel that can be used to supply energy. Waste feed stocks can include municipal solid waste, construction and demolition debris, agricultural waste, such as crop silage and livestock manure; industrial waste from coal mining, lumber mills, or other facilities; and even the gases that are naturally produced within landfills. Energy can be derived from waste that has been treated and pressed into solid fuel. Advanced waste-to-energy technologies can be used to produce biogas (methane and carbon dioxide), syngas (hydrogen and carbon monoxide), liquid biofuels (ethanol and biodiesel), or pure hydrogen. These fuels can then be converted into electricity.

Waste-to-Energy Technology Alternatives

The primary categories of technology used for waste-to-energy conversion are physical methods, thermal methods, and biological methods (Fig. 10).

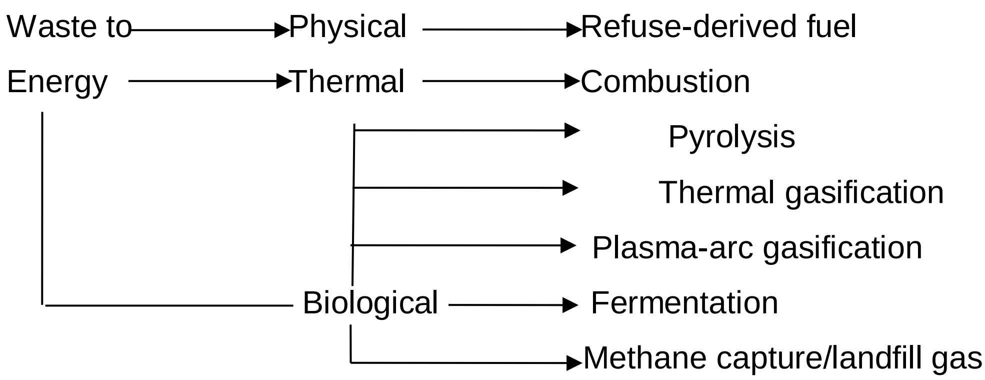

Fig. 10. Waste to Energy Technology tree. Sourse: (Machdonal, 1996; Sonesson, 2000)

A. *Physical:* Physical waste-to-energy technologies mechanically process waste to produce forms more suitable for use as fuel, producing refuse-derived fuel or solid recovered fuel. This process reduces the volume of the waste by up to 60%, and the residual material can then be compressed into pellets or bricks and sold as solid fuel. Burning Refuse derived fuel is more clean and efficient than incinerating municipal solid waste or other solid waste directly, but the processing adds to costs.

B. *Thermal:* Thermal waste-to-energy technologies use heat or combustion to treat wastes. Methods include the following:

1. Combustion: Municipal waste can be directly combusted in waste-to energy incinerators as a fuel with minimal processing, in a process known as mass burn. The step by step combustion is shown Fig. 11.

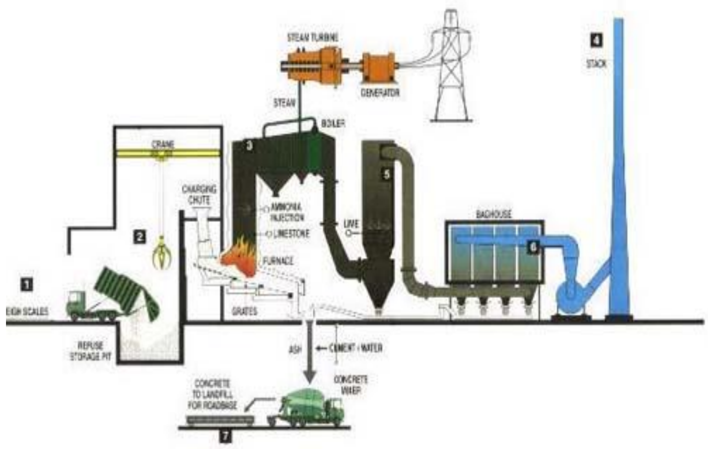

Fig. 11. Step-by-Step Operation of a Combustion Process Facility. Source: (BRTC, 2005; Garrett*, et al.,* 1970)

The Incoming trucks deposit the refuse into pits, where cranes then mix the refuse and remove any bulky or large non-combustible items such as large appliances. The refuse storage area is maintained under pressure less than atmospheric in order to prevent odors from escaping. The cranes move the refuse to the combustor charging hopper to feed the boiler.

2. Pyrolysis and Thermal gasification: Pyrolysis and thermal gasification are related technologies. The primary area of research for this technology is the scrubbing of the producer gas of tars and particulates at high temperatures in order to protect combustion equipment downstream of the gasifier and still maintain high thermal efficiency. The resulting gas was then combusted in stages, and the heat was used to turn water into steam, driving a steam turbine-generator.

Results and Discussion

Accurate and effective management of solid waste through waste-to-energy technologies serve as efficient means of renewable energy generation. It also provides a variety of benefits which makes it a good energy generation system. These benefits may be classified into three groups viz. environmental, economic and energy benefits:

1. The environmental benefits include: Elimination of malodorous compounds, reduction of pathogens, deactivation of weed seeds, production of sanitized compost, decrease in greenhouse gases emission, Reduced dependence on inorganic fertilizers by capture and reuse of nutrients, promotion of carbon sequestration, beneficial reuse of recycled water, protection of groundwater and surface water resources and improved social acceptance

2. The benefits in term of energy include: Anaerobic digestion is a net energy-producing process, a biogas facility generates high-quality renewable fuel, surplus energy as electricity and heat is produced during anaerobic digestion of biomass, anaerobic digestion reduces reliance on energy imports, such a facility contributes to decentralized distributed power systems and biogas is a rich source of electricity, heat, and transportation fuel.

3. The economic benefits associated with a biomass-to-biogas facility are:

Anaerobic digestion transforms waste liabilities into new profit centers, the time devoted to moving, handling and processing manure is minimized, Anaerobic digestion adds value to negative value feedstock, Income can be obtained from the processing of waste (tipping fees), sale of organic fertilizer, carbon credits and sale of power, Power tax credits may be obtained from each kWh of power produced, a biomass-to-biogas facility reduces water consumption, it reduces dependence on energy imports, and anaerobic digestion plants increases self-sufficiency.

4. Performance Evaluation of Energy Conversion Technologies: Generally, the performance and efficiency of the energy conversion technologies considered are high and suitable for application in Nigeria if properly implemented beside that, these technologies such as landfill gas capture, combustion, pyrolysis, gasification, plasma-arc gasification, and anaerobic digestion can be employed as a process of biogas production. Considering the efficiency of the various technologies as shown in the Table 3.1, any of the technologies would be an effective method of waste management as highlighted in this report.

Table 6. Efficiency of Energy Conversion Technologies

Technologies	Energy Value (kWh/Ton of Waste)

Landfill Gas	41-84
Combustion	470-930
Pyrolysis	450-530
Gasification	400-650
Plasma Arc Gasification	400-1,250

Source: (EIA, 2007; RISEAT, 1998)

The indiscriminate disposal of wastes in Nigeria which is a source of environmental pollution could be controlled by disposing food wastes into containers, from where gas suitable for cooking are produced. Production of cooking gas for household and energy for power generation is found to be possible by a special method of anaerobic decomposition of wastes. Biotechnology is found to be suitable method of waste management and energy generation.

5. Cost Effectiveness of Energy Conversion Technologies

There are many waste-to-energy technologies, but how many of these are cost effective? Waste to energy technology includes combustion, gasification, pyrolysis, anaerobic digestion, fermentation, and esterification. Some of these technologies are very cost effective, while others may not be as much so. Some use thermal processing, others use chemical processing, and still others use biochemical processing.

Municipal waste to electricity can help meet the energy needs of Nigerian homes, while biofuels created from waste can be used to power vehicles. Waste is abundant in Nigeria, and waste to energy programs take discarded organologies to turn this trash into electricity, heat, and fuel. Combustion is the burning of waste, to create energy in the form of heat, which can be used to make steam that is then turned into electricity. This type of waste to energy plant can use any type of burnable waste to create electricity, but care needs to be used to minimize the amount of toxins and pollutants in the smoke that is released.

Gasification and pyrolysis are some of the most effective waste to energy technologies available currently. These two technologies can be performed together to maximize the cost effectiveness. Pyrolysis needs an outside heat source, and this is supplied by the gasification process, making both processes together self-sustaining. This reduces the cost of the process, making them both more cost effective. Waste to energy in this manner can create several forms of energy. Anaerobic digestion is another possibility with waste to energy technology that is available today. The waste is put in specially constructed digesters, and no oxygen is allowed in. This allows the waste to break down much faster, releasing greenhouse gases including large amounts of methane. This process can also create heat from the large amounts of microbial activity as the biomass is decomposing.

Recommendations

The following recommendations are necessary and must be emphasized and achieved the technologies of energy generation from solid waste management is to be realized and domesticated in Nigeria.

1. Waste disposal acts and relevant Municipal regulations must be in place to support waste collection, recycling, transportation, disposal and operation. Laws must be enforced to ensure that waste is transported to regulated waste disposal areas. This would result in a sanitary environment void of dispersed waste and a reduction in environmental pollution in the communities. No one is immune from keeping these laws.

2.Improvement of the method of funding in order to enable successful implementation of sustainable waste management programs. This may be achieved by allowing greater participation of the private sector.

3. The Federal Government of Nigeria should incorporate energy from waste, biomass and biogas, as a key component of its energy production strategy. Currently, is not one of the key components of energy production. The focus has been more geared to conventional energy sources i.e. Fossil fuels, Hydro, Coal etc as evidenced in the Renewable Energy Action Program (REAP) document.

4. Scavenging should be properly coordinated for the purpose of deriving maximum economic benefits from such activities and also for the health and safety of those involved.

5. Education and awareness in the area of waste and waste management is increasingly important from a global perspective of resource management. Therefore, it is necessary.

6. Policies to foster Energy Efficiency through generation and distribution using appropriate waste-to-energy plants should be encouraged.

7. Supervision and financing of research and monitoring programs for pollution control and energy conversion technologies should be encouraged and supported.

8. The Government should encourage every effort to domesticate waste-to-energy technology in the country by providing the basic infrastructural facilities required.

9. Policies and regulations should be put in place to support energy production and sales from renewable resources. Examples of such policies based on best practices in the United States are the Renewable Portfolio Standards.

Conclusion

Energy is fundamental to all human activities. The existing MDGs cannot be achieved without access to energy. Energy is inevitable for poverty alleviation and the production of goods and services. Globally, more than 1.6 billion people live without access to electricity and 2.4 billion people are without modern energy services for cooking and heating.

Nigeria with a population of over 130 million and a few urban areas where the population is concentrated provides fertile grounds for municipal solid waste-to energy projects. The waste disposal sites in these concentrated urban areas provide a vast supply of renewable energy sources.

The inability of the existing energy sources to consistently meet the power demand needs in the urban and rural areas provides an opportunity for the public and private sector to explore alternative energy sources using existing energy conversion technologies of waste management. Methane gas which is created naturally through anaerobic waste decomposition is a readily available renewable energy source that can be collected and used as domestic cooking gas, or used directly as medium or high Btu gas for industrial use or to fuel turbine driven generators of electricity.

In terms of deliverables, the results of this research yielded:

- a demonstrated low-cost system for converting waste biomass into methane;
- optimization criteria for system operation with respect to various waste biomass influents;
- a market-ready sustainable energy technology;
- an environmentally-friendly means of biomass waste minimization with production of a beneficial end-product (soil conditioner).

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