# PLASMA ARC GASIFICATION FOR WASTE MANAGEMENT AND SUSTAINABLE RENEWABLE CLEAN ENERGY GENERALIZATION

FELIX N. C. ANYAEGBUNAM

(Sponsored by K.M. Onuoha, FAS)

**ABSTRACT**

Plasma gasification in waste to energy is one of the novel applications that were introduced many years ago. Landfill sites and incineration continue to be the primary methods used to dispose wastes with significant negative impact on the environment. Landfill releases methane which is 21 times more dangerous as a greenhouse gas than carbon dioxide. Incineration is often pushed as an alternative to land filling. However, it is a known fact that incinerator ashes are contaminated with heavy metals, unburned chemicals and new chemicals formed during the burning process. These ashes are then buried in landfill or dumped in the environment. Rather than making waste disappear, incinerators create more toxic waste that pose a significant threat to public health and the environment. Sustainable and successful treatment of MSW should be safe, effective, and environmentally friendly. In this application, plasma arc gasifies the carbon-containing materials in the waste to produce synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen, which can be used to produce energy through reciprocating engine generators - gas turbines and steam boilers in integrated gasification combine circle (IGCC), and/or liquid fuels. The in-organic waste materials are vitrified and runs out of the vessel's bottom as glass-like slag and reusable metal. The double benefit of waste management and energy production is realized from plasma gasification process.

*Key words and phrases.* Plasma physics, plasma gasification, waste to energy, syngas.

# 1. INTRODUCTION

Camacho, the former NASA scientist, used plasma technology to transform waste to energy in 1973. He showed that the process would produce useful gas that could be used for producing various forms of energy, and vitrified rock-like byproduct that could be used as construction aggregate (Camacho, S. L. 1996). The harmful attributes of landfills to environment are revealed (Youngchul B, Moohyun C, Soon-Mo H, and Jaewoo C, 2012). Consequently, the issues related to landfills, created an atmosphere for academia and industry to extend their research frontiers for new solutions that would be environmentally friendly.

Although plasma technology was introduced in the 1950s, adaptation of this technology to large-scale waste destruction, including gasification of waste and recovery of energy from the generated gas is new. Plasma gasification of municipal solid waste (MSW) is a fairly new application that combines well-established sub-systems into one new system (Dodge E. 2009).

In Plasma Gasification (http://www.recoveredenergy.com/ d _plasma.html) the MSW is gasified in an oxygen-starved environment to decompose waste material into its basic molecular structure. As opposed to incinerators, the waste does not combust in the gasifying plant. Plasma may be created in a variety of ways, including passing a gas between objects with large differences in electrical potential, as in the case of lightning, or by exposing gases to high temperatures, as in the case of arc welding or graphite electrode torches. Plasma arc torches utilize a combination of these techniques (Anyaegbunam F.N.C., 2013). A relatively small quantity of ionized gas is produced by an "arc igniter" and introduced between the electrodes contained in the body of the torch. The extremely intense energy produced by the torch is powerful enough to disintegrate the waste material into its component elements. The subsequent reaction produces syngas and byproducts consisting of a glass-like substance used as raw materials for construction and also re-useable metals. Syngas is a mixture of hydrogen and carbon monoxide (Blees, Tom 2008) and it can be converted into fuels such as hydrogen, natural gas or ethanol. The Syngas so generated is fed into a heat recovery steam generator (HRSG) which generates steam. This steam is used to drive steam turbine which in turn produces electricity. The cooled gas is then compressed and used to drive a gas turbine which in turn produces additional electricity. The integrated gasification combine circle (IGCC) energy thus produced is used partly for the plant load, while the rest can be sold to the utility grid. Essentially the inorganic materials such as silica, soil, concrete, glass, gravel, including metals in the waste are vitrified and flow out the bottom of the reactor. There are no tars, furans or ashes enough to pollute the environment.

Municipal solid waste is believed to be a source of renewable energy, and plasma arc gasification technology is one of the leading-edge technologies available to harness this energy (Pourali, M. 2010). The Waste is a sustainable fuel source and increasing day by day as population increases. Therefore, Plasma Gasification may be proven as a sustainable source of clean energy and environmentally safe solution for waste management.

## 1.1. Waste Handling and Treatment.

In most developing countries, wastes are commonly dumped in open dumps uncontrolled landfills where a waste collection service is organized. Developed countries, on the other hand have well organized waste management systems. Open dumping of waste cannot be considered as a long-term environmental method of disposal. The dangers of open dumping are many; health hazards, pollution of ground water, spread of infectious diseases, highly toxic smoke from continuously smoldering fires and foul odors from decomposing refuse. There is no defined method of waste handling and treatment but several million tons of MSW have been deposited in open dumpsites over the years. A new technology such as Plasma Gasification Technology may prove to be an environmentally friendly solution for the treatment of wastes.

1.2. **Plasma Technology.**

Plasma, often referred to as the "fourth state of matter", is the term given to a gas that has become ionized. An ionized gas is one where the atoms of the gas have lost one or more electrons and have become electrically charged. The sun and lightning are examples of plasma in nature. Important properties of plasma include the ability to conduct an electric current and to respond to electromagnetic fields. The term "plasma" was coined (Langmuir I., 1928) perhaps, because the glowing discharge molds itself into the shape of the Crooks tube. The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields, (Patel M. L, Chauhan J. S, 2012).

Artificial Plasma may be created by passing a process gas, which serves as a dielectric, between objects with large electrical potential differences. The potential difference and subsequent electric field causes ionization of the gas and electrons are pulled toward the anode while the nucleus (Chen, Francis F., 1984) pulled towards cathode. The current stresses the gas by electric polarization beyond its dielectric strength into a stage of electrical breakdown. The presence of this ionized gas allows the formation of an electric arc between the two electrodes, and the arc serves as a resistive heating element with the electric current creating heat which creates additional plasma that allows the arc to be sustained. A major advantage of the plasma arc as a resistive heating element is that it is formed in a gas and cannot melt or fail as can solid heating elements. Interaction between the arc and process gas introduced into the torch causes the temperature of the gas to be very high and the hot gas can exit the plasma torch at about $10{,}000^{\circ}C$.

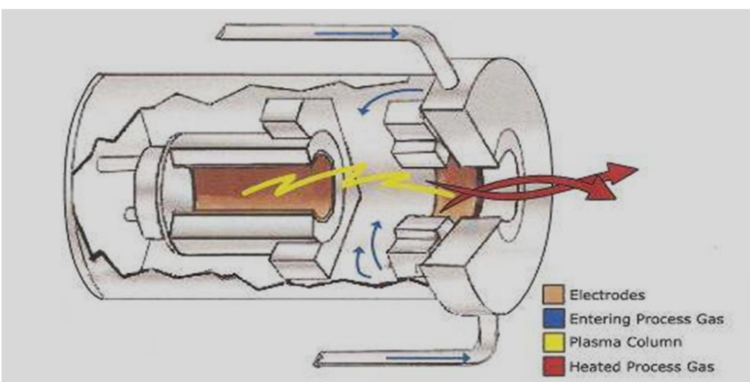



Figure 1. **Plasma Tourch**

The ability to increase the temperature of the process gas up to ten times higher than those attainable by conventional combustion makes plasma arc technology ideally suited for high temperature process applications such as gasification.

## 2. MATERIALS AND METHODS

Waste in Abuja-Nigeria is considered as a test case for this study. Information on waste collection and handling is supplied by Abuja environmental protection board (AEPB) and also from various municipal area councils in the Federal Capital Territory. Some workers at AEPB were interviewed to gather relevant information on the status of MSW collection and disposal. Various open dumpsites were visited and waste samples collected and analyzed. Useful information is also gathered from AEPB website: (www.environmentalprotectionboard.gnbo.com.ng) Data collection and analysis is based on the information about the six municipal area councils of Abuja with respect to 2006 population census. A survey is conducted on the status of solid waste generation in each of the municipal area councils. The area councils provided information based on collection and transportation. The data collected from the area councils and those obtained on their websites were analyzed and corrections made on average basis of the size of the area council. The sampling was done at the dumpsites and analysis done for the composition of MSW in each area council as per established guidelines issued by the United Nations Environment Program (UNEP).

**2.1. Municipal Solid Waste Generation and Characterization.** Solid waste generation studies are based on the information supplied by the local area councils. There are no regulations or standards to guide the collection and monitoring of the MSW. Less than 50% of the waste generated is collected. The MSW generation in Abuja is shown in Table 1. The rate of MSW generation in Abuja is about 0.67*kg/cap/day*.

**Table 1. Municipal Solid Waste Generation in Six Area Councils of Abuja**

| MUNICIPAL AREA COUNCILS | POPULATION | MSW /MT/d | Per capita waste Generation/kg/d |
|---|---|---|---|
| ABUJA | 2,245,000 | 1527 | 0.68 |
| ABAJI | 58,444 | 38 | 0.65 |
| BWARI | 227,216 | 150 | 0.66 |
| GWAGALADA | 157,770 | 104 | 0.66 |
| KWALI | 85,837 | 55 | 0.64 |
| KUJE | 97,367 | 44 | 0.67 |
| TOTAL | 2871634 | 1918 | 0.668 |

**Table 2. Waste Stream Composition**

| | ABUJA | ABAJI | BWARI | GWAGALADA | KWALI | KUJE |
|---|---|---|---|---|---|---|
| Putreserible | 53.2 | 52..5 | 50.8 | 51.9 | 54.5 | 55.0 |
| Plastics | 7.2 | 8.2 | 8.1 | 7.8 | 6.8 | 7.6 |
| Paper | 14.0 | 12.4 | 14.3 | 13.5 | 12.1 | 13.8 |
| Textile | 4.1 | 3.5 | 2.6 | 4.0 | 4.6 | 2.7 |
| Metal | 5.0 | 4,5 | 5.1 | 5.2 | 4.9 | 3,9 |
| Glass | 3.5. | 3.9 | 4.0 | 4.2 | 4.3 | 4.1 |
| Others | 13.0 | 15.0 | 15.1 | 13.4 | 12.8 | 12.9 |

The food consumption of residents of Abuja and the municipal area councils is essentially carbohydrate and vegetables just as in most part of Nigeria. This partly gives rise to higher percentage of organic component of the MSW. The AEPB does not provide separate solid waste management for the seven classifications of available solid waste. The majority of substances composing municipal solid waste include paper, vegetable matter, plastics, metals, textile, rubber and glass. Table 2 shows a comparative analysis of municipal solid waste composition in the six Municipal area councils of Abuja. It can be seen that great majority of the total solid waste generated in Abuja is organic as in most developing countries.

**2.2. Plasma Gasification Process.**

Gasification is a process that converts carbon-containing materials, such as municipal solid waste (MSW), coal, petroleum coke, or biomass, into a synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen. Gasification occurs (Anyaegbunam F.N.C., 2013) when a carbon-containing feedstock is exposed to elevated temperatures and/or pressures in the presence of controlled amounts of oxygen which may be supplied by air, oxygen enriched air (essentially pure oxygen), or steam. The global gasification reaction is written as follows; waste material is described by its global analysis, *CHxOy*), (Youngchul B, Moohyun C, Soon−Mo H and Jaewoo C, 2012):

$$CH_xO_y + wH_2O + mO_2 + 3.76mN_2 \rightarrow aH_2 + bCO + cCO_2 + dH_2O$$

$$+ eCH_4 + fN_2 + gC,$$

where $w$ is the amount of water per mole of waste material, $m$ is the amount of $O_2$ per mole of waste, $a, b, c, d, e, f$ and $g$ are the coefficients of the gaseous products and soot (all stoichiometric coefficients in moles). This overall equation has also been used for the calculation of chemical equilibrium occurring in the thermal plasma gasification with input electrical energy. The concentrations of each gas have been decided depending on the amount of injected $O_2$, H2O, and input thermal plasma enthalpy. The detailed main reactions are as follows:

$CH_4 + H_2^O \rightarrow CO + 3H_2$ ($CH_4$ decomposition-endothermic)
$CO + H_2O \rightarrow CO_2 + H_2$ (water gas shift reaction-exothermic)

$C + H_2O \rightarrow CO + H_2$ (Heterogeneous water gas shift reaction-endothermic) $C+CO_2 \rightarrow 2CO$ (Boudouard equilibrium-endothermic)
$2C + O_2 \rightarrow CO$

The $H_2$ and CO generated during the gasification process can be a fuel source. Therefore, plasma gasification process has been combined with many other technologies to recover energy from the syngas.

### 2.3. Plasma Gasification of Municipal Solid Waste (MSW).

Plasma gasification is an efficient and environmentally responsible form of thermal treatment (Dighe Shyam V., 2008) of wastes which occurs in oxygen starved environment so that waste is gasified, not incinerated. Westinghouse Plasma Corporation (WPC) has developed a plasma gasification system (Patel M. L, Chauhan J. S, 2012; Anyaegbunam F.N.C, 2013) which uses plasma heat in a vertical shaft cupola adopted from the foundry industry. The plasma gasification process is illustrated in Figure 2 below. The heart of the process is the plasma gasifier; a vertical refractory lined vessel into which the feed material is introduced near the top along with metallurgical coke and limestone. Plasma torches are located near the bottom of the vessel and direct the high temperature process gas into a bed of coke at the bottom of the vessel. Air or oxygen is introduced through tuyres located above the torches. The high temperature process gas introduced through the torch raises the temperature of the coke bed to a very high level to provide a heat reservoir and the process gas moves upward through the gasifier vessel to gasify the waste. The power of plasma gasification makes it environmentally clean technique. Plasma Gasification Plant (PGP) projects (Evans Steve D, 2009) are being developed by many gas plasma technology companies, and real benefits are obtained from this technology for the Municipal Solid Waste (MSW) disposal. (Plasma Gasification Plant Benefits for Municipal Waste Management, EzineArticles.com, available at http://www.articlesbase.com/literaturearti//cles/plasma-gasification-plant-benefits-for-municipal-waste-management-850915. html, accessed during December 2011). Additional heat

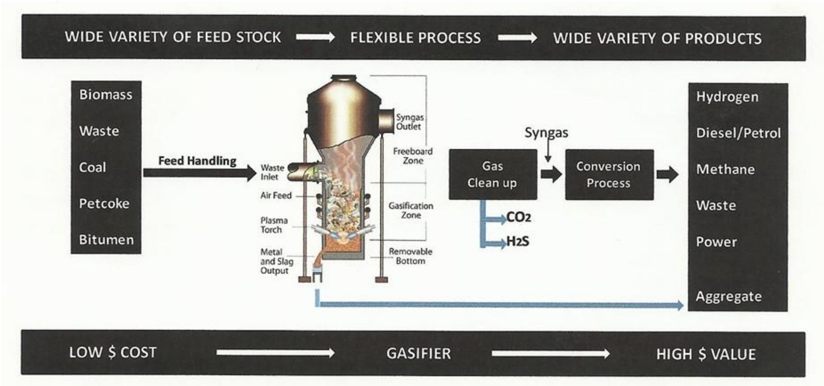



Figure 2. **Plasma gasification process**

is introduced from the reaction of the carbon in waste with the oxygen introduced through the tuyres to produce carbon monoxide in the gasification process. The hot product gas, passing upward though the waste breaks down organic compounds and dries the waste at the top of the gasifier. As the waste moves downward through the gasifier vessel, inorganic materials such as metal, glass and soil are melted and produce a two-phase liquid stream consisting of metals and a glass-like (vitrified) residue that flows to the bottom of the vessel. Discharge of the molten material into water results in the formation of metal nodules and a coarse sand-like material.

**2.4. Environmental Sustainability of Plasma Gasification.** Plasma gasification represents a clean and efficient option to convert various feed stocks into energy in an environmentally responsible manner (Nedcorp Group, 2009; Anyaegbunam F.N.C., 2013). In the plasma gasification process, heat nearly as hot as the sun's surface is used to break down the molecular structure of any carbon-containing materials - such as municipal solid waste (MSW), tires, hazardous waste, biomass, river sediment, coal and petroleum coke - and convert them into synthesis gas (product gas) that can be used to generate power, liquid fuels or other sustainable sources of energy.

The Georgia Tech PARF lab conducted several tests (Pourali, M. 2010) using their prototype plasma gasification units. The main supplies of the furnaces were artificial combination of materials to simulate typical average constituents of MSW based on US EPA. For the Ex-Situ experiments the MSW constituents were used and for In Situ experiments, soil was added to the MSW constituents to simulate a real landfill. The summary of the PARF lab experiment results are as follows:

1. The percentage weight loss of the MSW after plasma processing is 84% for ex-situ experiment where the MSW constituents alone were used, and 59% for in-situ experiment where soil was added to MSW to simulate a real landfill or dumpsite. And weight loss was significantly less than for ex-situ experiments.
2. The percentage volume reduction of the MSW after plasma processing was 95.8% for ex-situ experiments and 88.6% for in-situ experiment. Again, given that significant amount of soil was added to the mix in in-situ experiment, obviously, the soil was melted (vitrified) but did not gasify and consequently the volume reduction was reasonably different comparing with ex-situ experiment.

3. Toxicity Leaching text results for heavy metals (Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium and Silver) present after plasma gasification process are below detectable levels (BDL) in both experiments, and also far below the permissible standards established by US EPA.
4. Output Gas Composition: Table-3 shows the output syngas compositions for experiment without soil and with soil respectively in parts per million:

**Table 3. Output Gas Composition**

| Output Gas | Ex-Situ Experiment without soil (PPM) | In-Situ Experiment with soil (PPM) |
|---|---|---|
| Hydrogen (H2) | >20,000 | >20,000 |
| Carbon Monoxide (CO) | 100,000 | >100,000 |
| Carbon Dioxide (CO2) | 100,000 | 90,000 |
| Nitrogen Oxides (NOx) | <50 | 100 |
| Hydrogen Sulfide (H2S) | 100 | 80 |
| Hydrogen Chloride (HCL) | <20 | 225 |
| Hydrocarbons | >5,000 | >4,500 |

**PPM = parts per million.**

### 2.4.1. Low emissions.

Less than 0.01 NG/NM3 of Dioxins/Furans emission results in PG. The pollutants ($No_x$, $So_x$ and particulate matter are significantly low in PG Process see (Fig.3). Sulfur reports as Hydrogen Sulfide ($H_2S$) Easier to clean than $So_x$. Tars are cracked prior to leaving Plasma Gasifier.

**Comparison on waste-to-Energy Criteria Pollutants**

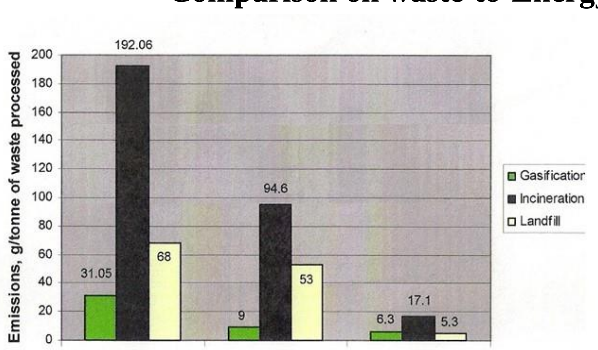
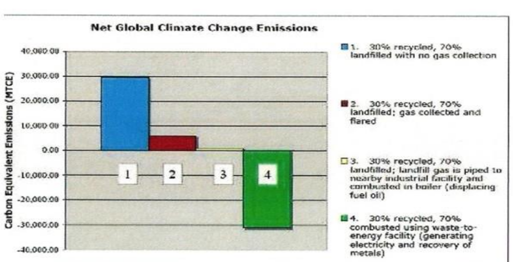



Figure 3. **Emissions in grams per ton of waste processed by different processes**




Data Source: Thomeloe SA. Weitz K. Jambeck J. Application of the U.S. Decision Support Tool for Materials and Waste Management. WM Journal 2006 August.

Figure 4. **Net climate change emissions for Plasma gasification are negative compared to other waste management options**

The rate of Carbon dioxide emission (Circeo L. J, 2012) per MWH of electricity produced shows (EPA document: www.epa.gov/ceanenergy/emissions.htm) that while incineration of MSW emits 2,988 pounds of CO2 per MWH of electricity produced, plasma gasification emits only 1,419 pounds per MWH. (Westingouse Plasma Corporation, $CO_2$ conversion-Nedcorp Group, 2009). Each plasma gasification application will have a different environmental profile, (Nedcorp Group, 2009) but in general terms a plasma gasification facility will have very low emissions of $NO_x$, $SO_x$, dioxins and furans. In summary, when compared to conventional incineration or traditional gasification technologies, the Plasma Gasification technology and its plasma torch systems offer the following benefits listed in table 4:

**Table 4. Plasma Gasification Compared to Incineration and Other Gasification Processes**

| Feedstock Flexible | Ease of Operation | Environmental Benefits | Flexible Product Delivery |
|---|---|---|---|
| A wide range of opportunity fuels can be accepted with limited pre-processing requirements | The Gasification Reactor Operates at ambient pressures allowing for simple feed system and online maintenance of the plasma torches | Operation is environmentally responsible creating a product gas with very low quantities of NOx, SOx, dioxins and furans | Syngas composition (H2 to CO ratio, N2) can be matched to downstream Process equipment by selection of oxidant and torch power consumption |
| Multiple Feed Stocks can be combined | Plasma Torches have no moving parts resulting in high reliability. Torch consumables are quickly replaced off line by plant maintenance personnel | Inorganic components get converted to glassy slag safe for use as a construction aggregate | Multiple gasification reactors are used for larger projects increasing availability of the gasification system |

## 2.5. Plasma Gasification an environmentally friendly sustainable solution for Municipal Solid Waste Management.

As we have seen from our Abuja test case, AEPB still practice dumping of the MSW in the outskirt of the township and open dumping creates huge Environmental Problems. The quantity and composition of the waste contribute much to the selection of the management solution. In fact, waste management is multi-disciplinary issue and involves various environmental, economic and community aspects. Hence, certain criteria should be satisfied for any waste management method desired.

### 2.5.1. Waste management criteria.

There is an emerging global (Rathi Sarika, 2007, Patel M. L, Chauhan J. S, 2012) consensus to develop local level solutions and community participation for better MSW management. Emphasis has been given to citizens' awareness and involvement for better (Beukering, 1999) waste management. A number of studies were carried out in the past to compare different methods of waste disposal and processing for different places. (Maimone, M., 1985) concluded that composting was the best option of waste management. (Powell, J.C., 1996) concluded that refused derived fuel was the best option. It can be inferred from the literature that no one method in isolation can solve the problem of waste management. The present study is an attempt to establish that the best feasible method of waste management shall involve plasma gasification method which will not only achieve environmental sustainability but also sustainable renewable energy solutions. The suitability of a particular technology for the treatment of MSW depends on a number of factors which include techno-economic viability, environmental factors, sustainability, accessed during December 2011), (Varma, R. Ajayakumar, 2009) and geophysical background of the location. The Plasma Gasification Process (Lisa Zyga, 2012,) seems to be a realistic solution for the MSW management. It is a process, that can get rid of almost any kind of waste by eliminate existing landfills, open dumps, and produce a clean renewable energy.

### 2.5.2. Land requirement Criteria.

The land and transportation facilities are basic requirement for MSW management. As per the provisions of (Municipal Solid Waste Management and Handling) Rules, 2000, the landfill site shall be large enough to last for 20-25 years (Patel M. L, Chauhan J. S, 2012). It is the general experience that the land requirement for development of the MSW landfill site is around 0.2 ha/MT of MSW generation per day with minimum requirement of 2.0 ha land area. The projected minimum land requirement for Plasma Gasification Process (PGP), (Nedcorp Group, 2009) is dependent on the processing capacity of the plant and ancillary processes that maybe included in the overall plant design. However, a standard IGCC configured plant having a capacity of 1000 M.T per day would require about 2.0 Hectares (5Acres) of land. Increasing the capacity of the plant to 3000 M.T. per day would increase land requirement to about 4.0 Hectares.

### 2.5.3. Sustainability Criteria.

The sustainability of any project depends up on the capital cost, running & maintenance cost, availability of raw materials and payback cost. Capital costs for a plasma gasification plant are similar to those for a municipal solid waste incineration power plant, but plasma gasification plants are more economical because the plant's inorganic byproduct can be sold to the market as bricks and concrete aggregate. Plasma gasification plants also produce up to 50% more electricity than other gasification technologies, (Pourali, M. 2010) hence, reducing the payback period. Nedcorp group plasma gasification system using Westinghouse Plasma Corporation plasma touches uses 2 to 5% of energy input to produce 80% of energy output (Anyaegbunam F.N.C., 2013). The raw material or fuel for the plant is readily available in abundance and increasing by the day. Typical plasma gasification for waste to energy plant with a feedstock of 3,000 MT of MSW per day is estimated to cost over $400 million for installation and will generate about 120MW of electricity (Pourali, M. 2010). Most of the Plasma Gasification Plants require 120 Kwh of energy per ton of MSW and 816 kwh electricity is generated from the process. It is also projected (Pourali, M. 2010) that each ton of MSW can produce 1.20MWh of electricity if an integrated gasification combine circle (IGCC) is used. As the technology continues to gain acceptance, the cost will decrease significantly. Thus, theoretically, plasma IGCC plant at 45% efficiency can generate about 1,035MWh of electricity from 1918MT of MSW.

### 2.5.4. Syngas-to-Liquids Alternative.

Plasma gasification of MSW also generates several sustainable energy outputs including liquid fuels, Fig.2. Rising fuel costs and a desire for energy independence have revived interest in another market for gasification technology: the production of liquid transportation fuels. Commonly called Fischer-Tropsch (FT) liquids, after the German inventors of the primary chemical conversion process (indirect liquefaction), STL can help increase fuel supply diversity and energy security. In STL, clean synthesis gas (syngas) from plasma gasification of waste or coal is converted to a liquid hydrocarbon or alcohol for use as fuel or otherwise. First, the syngas must be cleaned of sulfur and other impurities before it is reacted into its liquid fuel form. The FT process is one possible conversion path. FT catalysts are used to facilitate the formation of hydrocarbons or alcohols from the carbon monoxide (CO) and hydrogen (H2) in the syngas. The end product of the process can be determined by changing the catalyst, feed composition, and reactor conditions such as internal temperature and pressure. The main products of the FT process are typically straight-chain, saturated hydrocarbons, of the form CnH2n+2 (this class of molecule are called paraffin), from which gasoline and diesel can be refined. Fuel gases like methane and liquefied petroleum gas (LPG; mostly propane and butane) are usually also formed in small amounts by STL but are generally discouraged by the process designers. Different catalysts can facilitate the formation of alcohols like methanol, ethanol and propanol that can be used as fuel or fuel additives. Methanol to Gasoline (MTG) is another alternative path for STL production. In this route, syngas is reacted to form methanol, from which gasoline is then formed.

## 3. RESULTS AND DISCUSSION

Municipal Solid Waste Management is a great challenge to the Waste Managers, Scientists and Engineers. The quantity of Municipal Solid Waste generation is increasing and availability of land for the landfills or open dump disposal is decreasing day by day and hence most of the latest efforts focus on" Zero Waste" and/or" Zero Land filling" disposal methods. It is depicted from the data interpretation that; that average Municipal Solid Waste generation from the six municipal area councils of Abuja is about 1918MT/day (Table-1). The percentage of plastic waste present in municipal solid waste is about 8% on average. The Plasma Gasification Process of Municipal Solid Waste is a proven technology in which the weight is reduced by about 84% and the volume of organic matter reduced by more than 95%. The vitrified glass generated as residue from Plasma Gasification Process is also environmentally safe for toxicity leaching. The vitrified glass can be used for the construction work. The reaction processes in the gasifier produce mainly syngas (Hydrogen and Carbon monoxide). The PGP out-put gas is environmentally safe. Plasma Gasification technology and its plasma torch systems when compared to incineration or traditional gasification offer unique environmental benefits. Operation is environmentally responsible creating a product gas with very low quantities of $NO_x$, $SO_x$, dioxins and furans. Inorganic components get converted to glassy slag safe for use as a construction aggregate. The fuel gas emissions are also within prescribed limit, thus, the process is environmentally safe in terms of rate of Carbon dioxide emission (Circeo L. J, 2012) per MWh of electricity produced in comparison to different processes such as incineration and land filling. The land requirement for management of Municipal Solid Waste through landfills would be around 384ha for 1918MT/day. However, processing of 3000MT/day by plasma gasification process will require only about 4ha of land, (Nedcorp Group, 2009). The reduction in the space required for the MSW management by PGP is very significant. This is positive for the fast-growing Cities where land resources are limited. The Plasma Gasification Processing (PGP) plants will generate renewable energy such as power and liquid fuels and these can be used by the local utility through national grid or sold to chemical companies. The PGP plants conserve fossil fuels by generating electricity and liquid fuels from MSW. It has been estimated that one ton of MSW decomposed in a gasifier rather than land filled reduces greenhouse gas emissions by 1.2 MT of carbon dioxide. Hence, there will be reduction of over 2300 MT/day of land filled greenhouse gas emissions for the 1918 MT of MSW which, in addition, can also produce about 1035MWh of electricity with Plasma gasification IGCC configuration.

The Municipal Solid Waste management is a challenge due to its increasing quantity and limited land resources. This is the reason that most of the latest efforts focus on" Zero Waste" and/or" Zero Landfilling" which is certainly expensive (Shekdar Ashok V., 2009) for weaker economies. Developing countries, though poor should develop areaspecific solutions to their problems (Henry et al., 2006) in the MSW management. Application of Plasma Gasification Process (PGP) in waste to energy, relieves the pressure on distressed landfills, and offers an environmentally benign method (Tom Blees, 2008) of disposing MSW. Municipal solid waste is considered as source of renewable energy, and plasma gasification technology is one of the leading-edge technologies available to harness this energy. In recent years, the US government officially declared the MSW as a renewable source of energy, and power generated through the use of MSW is considered green power and qualified for all eligible incentives. Plasma technology, therefore, is an economic and abundant source of renewable energy, and a reliable source of power.

## 4. CONCLUSION

Considering many applications of Plasma Gasification Process, the profit potential of plasma conversion (Blees Tom, 2008) is tremendous. Private companies could build facilities in developing countries and it would naturally be in their financial best interest to develop the garbage collection infrastructure to support their business, indirectly the collection system will be improved. Thus, the multiple benefits of waste management by plasma gasification can be exploited.

Plasma gasification converters represent the ultimate in recycling process; making virtually 100% of the waste a household normally produces into usable and even valuable end products. There would be no need to have two garbage pickups running, - one for trash and one for recyclables that people have perhaps been conscientious enough to separate. The plasma gasification process of MSW has all the merits of adoption, even though there are many disagreements among scientists and policy makers on these matters, there is, however, consensus that alternative sources of energy that are sustainable, environmentally friendly and regionally available must be the best choice. However, skepticism about the technology, lack of historical data, volatile price of crude oil, a mislabeling of plasma gasification technology as another type of incineration and a lack of government sponsored development and projects in plasma gasification, have contributed to the lack of progress in the development and utilization of this technology.

The sustainability of any solid waste management system depends (Pradhan U. M, 2008) on numerous factors; however, the most important factor is the will of the people and governments to change the existing system and develop something better. For any technology to be successful, the government should take the required initiatives and sincere commitment to drive the process of development.

**Acknowledgement**

I am grateful to the staff of Abuja Environmental Protection Board (AEPB), and of the six municipal area councils of Abuja who provided me with relevant information, without of which this study might not be possible.

## References

Anyaegbunam F.N.C, (2012), Feasibility Study for Plasma Power Project in Abuja, *BPP publications*, Vol.1, pp12-37. Jan; 2012.

Anyaegbunam F.N.C, JVL Capital (2012), Plasma Power Project Feasibility Report, Brain-Fintek Plasma Power Limited, *BPP publications, Vol.2, pp32-60. July 2012.*

Anyaegbunam F.N.C., (2013), Plasma Gasification for Waste destruction and Power Generation in Nigeria, *International Journal of Engineering Research* & *Tech.* Vol.2, pp1067-1079 (July 2013).

Anyaegbunam F.N.C., (2013), Sustainable Power Generation by Plasma Physics, *American Journal of Engineering Research*, Volume 02, Issue-08, pp65-75.

Beukering, (1999), Waste recovery in Bombay: a socio-economic and environmental assessment of different waste management options, *Third World Planning Review* **19**(2), pp 163-187.

Blees Tom, (2008), Prescription for the Planet, the Painless Remedy for our Energy & Environmental Crises, eds, ISBN: 1-4196-5582-5, ISBN-13: 9781419655821 Library of Congress Control Number: 2008905155, pp524-536.

Camacho S. L., 1996), Plasma Pyrolysis and Vitrification of Municipal Waste, U.S. Patent No. 5,544,597, Aug. 1996.

Chen, Francis F. (1984), in Plasma Physics and Controlled Fusion, eds, Plenum Press, ISBN 0306413329, pp8-17, 1984.

Circeo L. J, (2012), Plasma Arc Gasification of Municipal Solid Waste. Georgia Tech Research Institute, Environmental Science and Technology Program, Electro-Optical Systems laboratory. Research Report 3.pp1-25.

Dighe, Shyam V. (2008), Westinghouse Plasma Corporation, Madison, Pennsylvania, USA, Plasma Gassification: a proven technology. Proceedings of NAWTEC16, 16th Annual North American Waste-to-Energy Conference, May 19-21, 2008, Philadelphia, Pennsylvania, USA.

Dodge, E. (2009), Plasma Gasification: Clean Renewable Fuel Through Vaporization of Waste. Emerson Process Management. WaterWorld. Com, Waste Management world. Vol. 10, issue-4, pp231-240.

Evans Steve D, (2009), Plasma Gasification Plant Benefits for Municipal Waste Management, EzineArticles.com. pp14-25.2009.

Gomez P, (2009), Thermal plasma technology for the treatment of wastes: A critical review, Journal of Hazardous Materials 161(2-3), pp614-626. 2009.

Henry E, (2006), Country report, Municipal solid waste management challenges in developing countries - Kenyan case study, Waste Management and Research Report 26, pp92-100.

Langmuir I. (1928), Oscillations in ionized gases, Proceeding of National academy of science, U.S. 14(8), pp628. 1928.

Lawrence Bibber and Erik Shuster, DOE/NETL (2007), Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility [PDF-1.3KB], US-DOE/NETL Report, pp10-15. April 2007.

Lisa Zyga, (2012), Plasma Gasification Transforms Garbage into Clean Energy, Science Blogger, InventorSpot.com, via: Popular Science, pp12-18, 2012.

Maimone, M., (1985), An application of multi-criteria evaluation in assessing MSW treatment and disposal systems, Waste Management and Research Report 3, pp217-231.

Nedcorp Group (2009), Environmentally Friendly Waste Destruction and Sustainable Renewable Energy, *A feasibility document of Nedcorp group*, pp3-19, July 2009.

Patel Munna Lal, Chauhan Janardan Singh (2012), Plasma Gasification: A Sustainable Solution for the Municipal Solid Waste Management in the State of Madhya Pradesh, India, *International Journal of Environmental Sciences*, Volume 3, No 1, 2012.

Pourali, M., (2010), Application of Plasma Gasification Technology in Waste to Energy-Challenges and Opportunities, *The IEEE Xplore digital library (Institute of Electrical and Electronics Engineers)*, **1**(3), pp125-130.

Powell, J.C., (1996), The evaluation of waste management options, *Waste Management and Research Report* 14, pp 515-526.

Pradhan Upendra Mani, (2008), Sustainable Solid Waste Management in a Mountain Ecosystem: Darjeeling, WestBengal, India, *A Thesis Submitted to the Faculty of Graduate Studies In Partial Fulfillment of the Requirements For the Degree of Master of Natural Resources Management, Faculty of Environment Earth and Resources Natural Resources Institute University of Manitoba*, pp34-79. November, 2008.

Rathi Sarika, (2007), Optimization model for integrated municipal solid waste management in Mumbai, India, *Environment and Development Economics* Vol.12, pp105-121.

Shekder Ashok V., (2009), Sustainable solid waste management: An integrated approach for Asian countries, *Waste Management Report* **29**(4), pp1438-1448.

Varma, R. Ajayakumar, (2009), Technoligical Options for Treatment of Municipal Solid Waste with special reference to Kerala, *Workshop on Public Office Sanitation at State Municipal House on 25th Sept 2009*, published on website in 2011.

Department of Physics/Geology/Geophysics,
Federal University Ndufu-Alike, Ikwo,
Abakaliki.

*E-mail address*: braintech_ict@yahoo.com