Plasma Gasification For Waste Destruction And Power Generation Innigeria

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ABSTRACT

Among the greatest challenges of Nigerian government today are Electricity generation and Municipal Solid waste management. Electric power demand far exceeds generation and distribution. Less than 4000MW of electricity is available for over 160 million people. The major cities of Nigeria are littered with wastes in open dumps which are dangerous to health and environment. Sustainable and successful treatment of MSW should be safe, effective, environmentally friendly and economically viable.In plasma arc gasification, the organic waste materials are gasified to generate a syngas and steam which can be used to generate electricity by integrated gasification combine cycle. This study describes the basics of this technology, reviews the power situation in Nigeria andthe benefits of implementation of this technology in waste to electric power generation. It might be proven as an Environmentally Safe and Sustainable economic Solution for waste destruction and alternative source of clean power generation in Nigeria.

KEYWORDS:*Plasma arc gasification, waste to energy, syngas, Municipal Solid Waste, Power generation.*

1.0.Introduction

Nigeria, situated on the West Coast of Africa, occupies 92 million hectares of land or 923,773 square kilometers (about 76% is arable) and is home to an estimated population of 160 million people. With a GDP of US$196 billion in 2010, US$230 billion in 2011 and an average annual growth rate of 7%, the Nigerian economy is at present one of the strongest economies in Sub Saharan Africa and this is expected to be sustained in the years to come yet possessing a huge potential to grow. Nigeria is a Federal Republic and gained independence on 1st October, 1960. It comprises of 36 States and the Federal Capital Territory, Abuja. There are 3 tiers of Government, namely Federal, State and Local Government. They are administered by the President, Governors and Local Government Chairmen respectively. The Federal Capital Territory is administered by a Minister appointed by the President. There are also 3 arms of Governance, namely Executive, Legislature and Judiciary. The Legislature is bi-cameral made up of the Senate and the House of Representatives. Growth has been broad based across all the major sectors of the economy, namely oil & gas, agriculture, commercial activities, construction, financial services, hotel & tourism and real estate.

The table below provides a selection of recent macro-economic indices on Nigeria.

Table 1- NIGERIA MACRO ECONOMIC INDICIES

NIGERIA - MACRO ECONOMIC INDICES					
PARAMETERS	**2007**	**2008**	**2009**	**2010**	**2011**
GDP at current market prices (N bn)	20,941	24,665	25,225	29,498	35,441
GDP at current market prices (US$ bn)	164	208	170	196	230
GDP per capita (N'000)	145	164	163	186	211
GDP per capita (US$)	1,149	1,391	1,098	1,232	1,371
Real GDP growth (%)	7	6	7	8	7

Inflation Rate (12 month moving av %)	5	12	13	14	11
Population (mn)	145	149	154	159	168
Current-account balance (% of GDP)	17	14	8	6	4
External reserves (US$ bn)	51	53	42	32	32
Exchange rate N : US $ (av)	127	121	162	153	159
Prime Lending Rate (end period)	17	16	19	16	17
Maximum Lending Rate (end period)	18	21	24	22	23
Manufacturing Capacity Utilisation (%)	54	54	55	56	57
Source : CBN Annual Report 2011[1]					

Nigeria expects to sustain the growth trend as depicted below:

Table 2 - NIGERIA - FORECAST INDICES 2012

NIGERIA - FORECAST INDICES 2012	
KEY INDICATORS	**2012**
Real GDP growth (%)	6
Consumer price inflation (av %)	7
Budget balance (% of GDP)	(2)
Current-account balance (% of GDP)	8
Commercial banks' prime rate (av %)	15
Exchange rate N : US $ (av)	158
Source: Economist Intelligence Unit	

1.1. THE CURRENT STATUS OF ELECTRICITY SUPPLY IN NIGERIA

The state of electricity supply to any nation is a function of several factors. Among such factors are the quantum of energy deposit in such nation, the level of electricity generating technology coupled with the available and effective capacities, electricity demand growth rate, the institutional framework for electricity generation, supply and distribution coupled with the pricing policy, the operational efficiency of the institutional framework etc.
Available information without rigorous data analysis show that Nigeria is a primary energy store house accommodating such resources as coal and lignite, natural gas, crude oil, solar, hydro, nuclear, wood fuel, geothermal, tide, biogas and biomass. In spite of the vastness of these resources in Nigeria, only four sources (coal, crude oil, natural gas and hydro) are currently being utilized in processed forms while two others(wood fuel and solar) are used in their crude forms for heating, cooking and lighting or waste.

Nigeria's primary energy resources are in excess of its domestic electric energy requirements such that it should not experience electricity supply inadequacy. But it's very unfortunate that the biggest problem in Nigeria is electricity crisis. A review of current power generation in Nigeria shows that the total grid capacity is 8,876 MW and power distribution has peaked at an all-time high of 3,653 MW[1]. Thus available power is less than 41% of the total installed

Total installed capacity from thermal (gas and steam) and hydroelectric technologies as at 1999 was 5,860 mw out of which about 5,400 mw (92.2%) constituted available capacity while the effective capacity was 1600 mw (27.3%). The transmission grid consisted of about 5,000km of 330 KV lines and also about 6,000km of 132 kV lines which were heavily overloaded.

Given the foregoing developments in the Nigerian electricity market, especially PHCN's devices to allocate available electricity to consumers, it is evident that the quantum of electricity sales to consumers do not in reality reflect in any form the actual demand for electricity in the country. At best it merely connotes what PHCN could supply. In view of the implications of the on-going electricity supply crisis in the economy, many Nigerians have been pauperized and made miserable. In sum, the current status of electricity supply in Nigeria reflects that of an electricity supply crisis in which industrial growth and socio-economic development paces are kept below what is attainable by the economy.

Table.3 - ELECTRICITY PLANTS CAPACITY UTILISATION IN NIGERIA (1999)

ELECTRICITY PLANTS CAPACITY UTILISATION IN NIGERIA (1999)					
Plants		Installed Capacity		Available Capacity	
Type	Location	MW	% Total	MW	% of Installation
Thermal (Gas)	Afam I-II	580	9.9	580	100.0
	Delta I-II	840	14.3	312	37.1
	Ijora	60	1.0	60	100.0
	Sapele	280	4.8	-	-
Thermal (Steam)	Egbin	1,320	22.5	-	-
	Sapele	680	16.4	348	51.2
Hydro	Kainji	960	16.4	520	54.2
	Jebba	540	9.2	140	25.9
	Shiroro	600	10.2	-	-
	Total	5,860	100.0	3,000	51.0
Source : PHCN					

1.2. POWER DEMAND

As at 2004, Total installed generation capacity was 6,102MW (NEPA and IPPs), but only a maximum of 3,300MW has been produced at any given time in the history of the sector. Between 1999 and 2003, actual generation increased by about 200% from 1,080 to 3,300. While installed capacity was raised to about 5,902MW from 2,257MW in the same period. According to the CBN Annual Report for the year ended 31 December 2005, the quantum of electricity generated declined in 2005. At 2,687.1 megawatt hour (MWH), aggregate electricity generation fell by 2.8%, in contrast to the increase of 15.2% in 2004. The installed electricity capacity of the PHCN stood at 5,800MW, while that of the Independent Power Plants (IPPs) was 300MW. Thus, PHCN accounted for 99.5% of total electricity generated, while the IPPs accounted for the remaining 0.5%.

While it is difficult to properly estimate the current level of electricity demand, various authoritative sources have pegged demand for electricity at 6,000MW per annum. This implies that Nigeria is only generating about 45% of current local demand. However, this figure could be more as demand in Nigeria can be categorized into two – those who are connected to the grid and those who do not have access to electricity. In addition, those connected to the grid can also be segmented into two – legal consumers (that is, accounted for by the PHCN) and the illegal customers (unlawful connection to the national grid). Industry sources stipulate that demand for electricity in Nigeria is growing at an estimated 7% yearly and according to PHCN, this peaks energy demand at 8000MW, 2000MW higher than the estimate of 6000MW. However, the Ministry of Power and Steel has estimated that the current estimated demand for electricity in urban areas alone is 10,000MW.

Since, demand for power exceeds supply; PHCN usually embarks on load shedding in periods of extremely low supply. In the last quarter of 2006, due to significant number of problems experienced, total generation capacity which was in the region of 3000 to 3200 MW dropped significantly by 60% to less than 1500 MW. As a result, the country has been experiencing the worst black out and most erratic power supply since 1999.

2.0.Plasma Arc Gasification Background

Plasma arc technology was developed and employed in the metal industry during the late 1800s to provide extremely high heat. During the early 1900s, plasma heaters were used in the chemical industry to manufacture acetylene fuel from natural gas. Plasma Arc heaters received renewed attention when the United States NASA Space program, during the early 1960s, evaluated and selected Plasma Arc Heating technology for simulating and recreating the extreme high heat of reentry into the earth's dense atmosphere encountered by spacecraft from orbit. Using a water-cooled copper electrode, a 50 Mega Watt plasma arc heater was used to convert electricity into heat in order to test the reentry heat shield material at NASA.Utilizing the same plasma technology, scientists who previously worked for NASA, have refined and improved the plasma arc technology inefficiency, cost, and wider user applications; the lead NASA scientist, Dr. S.L. Camacho was the first to use this technology to convert waste to energy[2]. Thegaseous emission to the atmospherewere limited and very much under control. Waste materials are processed without any fly ashes that would require to be sent to a landfill.

The environmental regulations are becoming more stringent andlandfills are becoming outmoded. The harmful attributes of landfills to environment are also revealed [3]. They suggested that Sustainable and successful treatment of waste should be safe, effective, and environmentally friendly.

Plasma arc technology is not new.However, adaptation of this approach to large-scale solid waste disposal, including gasification of waste and recovery of energy from the gas generated is new.As noted by [4]"Plasma gasification of mixed solid waste (MSW) is a fairly new application that combines well-established sub-systems into one new system. The sub-systems are waste processing and sorting, plasma treatment, gas cleaning, and energy production.

In Plasma Arc Gasification (PAG)(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. It does not combust the waste as in the incinerators. 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 torchesutilize a combination of these techniques[5]. 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 presence of this ionized gas allows the formation of an electric arc between the 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. Interaction between the arc and process gas introduced into the torch causes the gas to reach very high temperatures, often nearly as hot as the sun's surface. The ability to increase the temperature of the process gas to temperatures two to ten times higher than those attainable by conventional combustion makes plasma arc technology ideally suited for high temperature process applications such as gasification of waste.The extremely intense energy produced by the torch is powerful enough to disintegrate the MSW into its component elements. The subsequent reaction produces syngas and byproductsconsisting of a glass-like substance used as raw materials for construction, and also re-useable metals. Syngas is a mixture of hydrogen and carbon monoxideand 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 turbinewhich in turn produces electricity. The cooled gas is used to drive a second turbine to generate additional electricity – The integrated gasification combine circle (IGCC) [5] thus produce adequate electricity, part of which is used for the plant's loadand the rest of the power generated is sold back 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 topollute the environment.

2.1 Plasma Arc Gasification 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.Westinghouse Plasma Corporation ("WPC") is recognized as one of the world leaders in the development of plasma arc torch technology (Fig.1) and in the implementation of this technology. A major advantage of the WPC torch design is that it takes advantage of the ability of plasma to respond to magnetic fields by utilizing a rotating magnetic field to manipulate the attachment point of the arc on the electrodes to provide extended electrode life and reduced maintenance costs.

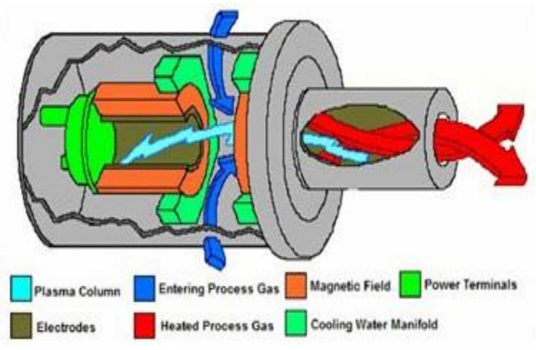

Figure 1: Westinghouse Plasma Torch Technology

Gasification is a process that converts carbon-containing materials, such as coal, petroleum coke, municipal solid waste, or biomass, into a synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen.Gasification occurs 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.Gasification accomplished through the use of controlled amounts of air or oxygen ("starved air gasification") produces a product gas composed primarily of carbon monoxide plus smaller amounts of hydrogen produced by reaction between carbon and moisture in the feedstock.

The principal advantages of gasification as opposed to direct combustion (incineration) for the recovery of energy from wastes such as Municipal Solid Waste (MSW) include:

- Production of a gaseous product that can be combusted more efficiently than a solid fuel, resulting in decreased requirement for excess air while reducing the potential for formation of products of incomplete combustion (PICs). This results in a reduction in the volume of emissions and lower total emissions when treated to the same concentration standards.
- Ability to clean the product gas prior to combustion, resulting in further reductions in emissions.
- Ability to utilize the Integrated Gasification Combined Cycle (IGCC) process for generation of electricity which results in much higher thermal efficiencies (40-45% energy recovery as electricity as opposed to 20-25 percent for mass burn facilities).
- The product gas can be transmitted by pipeline for use at locations at significant distances from the gasification facility.

Plasma gasification represents a clean and efficient option to convert various feed stocks into energy in an environmentally responsible manner [5]. Below are the environmental benefits of this process for power generation:

Gasification occurs in an oxygen starved environment, so feed stocks are gasified, not incinerated. Due to the high operating temperatures in the plasma gasification process:

- Produces no bottom ash or fly ash that requires treatment or landfill disposal.
- Metals not recovered from the waste stream prior to processing and most metallic compounds are reduced to their elemental state and recovered in a form that permits recycling.
- Non-combustible inorganic materials such as glass, concrete, and soil are melted and vitrified, producing an environmentally stable glass-like residue that can be sold for use as construction aggregate.
- The high heat output from the plasma torches in combination with the heat reservoir provided by the coke bed at the bottom of the vessel permits the plasma gasifier to accommodate wide variations in feedstock composition and characteristics.
- The absence of moving parts in the gasifier in combination with the high temperature and flexibility of the plasma heating system makes it possible to process materials such as carpet and tires that are difficult to process in conventional incinerators or other gasification processes.
- The gasifier operates under a slight negative pressure, minimizing the potential for escape of the product gas.
- Continuous discharge of the molten residue through the coke bed at the bottom of the vessel eliminates the need to maintain a molten pool of residue in the vessel and associated problems with freezing of taps required for discharge of the residue.
- Each plasma gasification application will have a differing environmental profile, but in general terms a plasma gasification facility will have very low emissions of NOx, SOx, dioxins and furans.

3.0 Waste Destruction and Power Generation Mechanism

Plasma gasification represents a clean and efficient option to manage waste in an environmentally responsible manner. The plasma gasification technology is ideally suited to process waste such as Municipal Solid Waste ("MSW"), common hazardous waste, industrial waste, chemical waste, sediment sludge and biomass. It can also vitrify fly ash from incinerators and any other types of ash. Converting waste into various energy outputs or power reduces reliance on the use of conventional fossil based fuels by using readily available waste.

In Nigeria like most developing countries, wastes are commonly dumped in open dumpsuncontrolled landfills where a waste collection service is organized. Open dumping of waste is not a long-term environmental method of disposal. The dangers of open dumping are numerous; health hazard to, pollution of ground water, spread of infectious diseases, highlytoxic smoke from continuously smoldering fires, foul odors from decomposing refuse and emission of greenhouse methane gas. However, several million tons of waste has been deposited in open dumpsitesacross the country over the years.A new technology such as

Plasma Arc Gasification Technology may prove to be an environmentally friendly solution for wastes destruction and power generation in the country.

Plasma was described [6] as "radiant matter" The nature of the Crookes tube "cathode ray" matter was subsequently identified by British physicist Sir J.J. Thomson in 1897. The term "plasma" was coined[7] perhaps,because the glowing discharge molds itself to 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,[8].

3.1 Gasification Process

The global gasification reaction is written as follows; waste material is described by its global analysis, CHxOy),[3]: $CH_xO_y + wH_2O + mO_2 + 3.76mN_2 \rightarrow aH_2 + bCO + cCO_2 + dH_2O + eCH_4 + fN_2 + gC$

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, H_2O, and input thermal plasma enthalpy.

The H2 and CO generated during the gasification process can be a fuel source for power generation.

3.2 Plasma Gasification of Municipal Solid Waste (MSW)

Plasma gasification is an efficient and environmentally responsible form of thermal treatment [9] 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[10]; [5] which uses plasma heat in a vertical shaft cupola adopted from the foundry industry. The plasma gasification process is illustrated in Fig. 2 below,[5]. 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 gasifying vessel to gasify the waste. The power of plasma gasification makes it environmentally clean technique. Plasma Gasification Plant (PGP) projects[11] arebeing developed by many gas plasma technology companies, and there are real benefits to be obtained from this technology for Waste destruction.

Additional heat is introduced from the reaction of the carbon in the 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 very similar to the black sand beaches produced in Hawaii when lava flows into the sea.

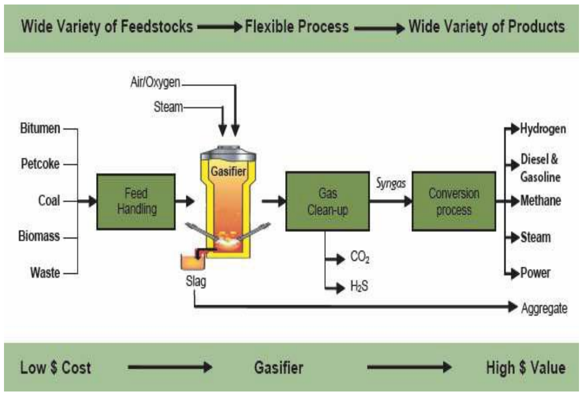

Fig. 2 Plasma gasification process

3.3 Power Generation: Integrated Gasification and Combined Cycle (IGCC)

In this case the product gas would be cooled prior to clean-up by passing through a heat recovery steam generator (HRSG) and the recovered heat used to generate steam. The cool gas would then be cleaned using readily available technologies, compressed, and used as fuel in a combustion turbine driving an electric generator. The hot turbine exhaust gas would pass through a second HRSG to produce additional steam prior to passing through a final emission control system designed to remove trace organics, metals and particulates prior to emission to the atmosphere. The steam from both HRSG units would be combined and used to produce additional electricity using a steam turbine generator.

3.4 Scalability of the Plasma Power System

The following diagram (Fig.3) illustrates typical plant layout configuration for a plant having process capacity of 3000 MT per day Municipal Solid Waste. This demonstrates the relative ease by which plants can be expanded to meet increasing loadings through the use of standardized process modules with capacities of 500 to750 MT/day. Note that in this example, a standby module has been included in the design to assure that processing capacity can be maintained during periods of scheduled maintenance.

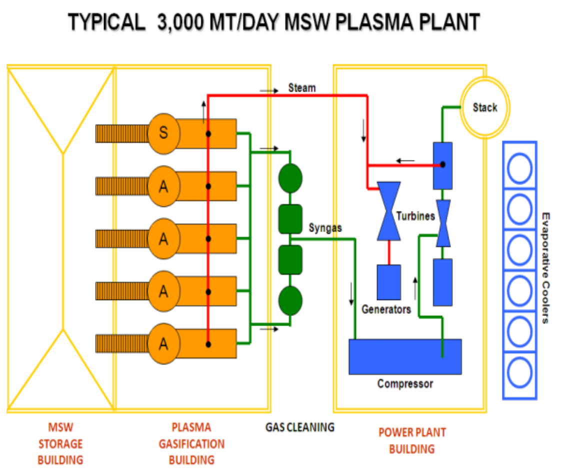

Figure 3: Plasma gasification facility using Integrated Gasification Combined Cycle (IGCC) for power generation

It should also be noted that a similar configuration could be achieved by adding modules to the 1000 MT/day facility. The ability to increase capacity by adding modular components as waste loading increases is an important advantage to the plasma gasification process for power generation.

Efficiencies of Scale

As with many industrial processes, increasing the size of the project increases efficiency. In the case of plasma gasification for power generation, these increases result from a combination of factors including proportionately smaller increases in internal plant loads on a per unit basis and increased efficiency of electrical generation through the use of larger units capable of operating at higher temperature and pressures that result in higher thermal efficiencies. The expected effects of increasing plant capacity on thermal efficiency and power output per ton of material processed are summarized in Table 4 below.

Table 4 Economies of Scale in Combined Cycle Plasma Gasification

		Combined Cycle (IGCC)				
Plant Capacity MT/day	**Heat Input (MWht**	**Gross Mwe**	**Net Mwe**	**Plant Load**	**MWh/ MT MSW**	**Overall Efficiency %**
500	83.3	33.7	26.7	6.93	1.28	32.1
2500	416.4	186.9	152.1	34.76	1.46	36.5
5000	832.7	393.42	323.8	69.52	1.55	38.9

We notice from the table that for a combine circle power generation with plant capacity of 500MT/day, power generation is 26.7MW and the overall efficiency is 32.1%. If the capacity is increased to 5000MT/day the overall efficiency increases to 38.9% and about 323MW of Electric power will be generated.

4.0 Environmental Sustainability of Plasma Arc Gasification.

Plasma gasification represents a clean and efficient option to convert various feed stocks into energy in an environmentally responsible manner [5]. 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 Electric power, liquid fuels or other sustainable sources of energy.

Burning or incineration does not occur in a plasma gasification unit, and so compared with other thermal

conversion processes, gasification is completely different than incineration (Table 5b).

Table 5a. Plasma Gasification Compered 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 (H_2 to CO ratio, N_2) 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

Virtually any material, including low-level radioactive waste under certain conditions, can be reduced using plasma gasification. Materials that can be safely and effectively treated include coal, sludge, incinerator ash, hazardous fly ash, automobile shredder residue, medical waste, pathological wastes, PCB oil pyrolysis products, ferrous chromium waste, ferro-manganese reduction compounds, titanium scrap melt, niobium recovery products, electric arc furnace dust, Portland cement manufacturing waste, paper, cardboard, plastics, fiberglass insulation and other products, asbestos, wood, glass, ceramics, rubber, tires, asphalt shingles, used roadway asphalt, oil sands, sewage sludge, harbor sludge, composite materials containing resins, linoleum, plastic piping, solvents, paints, and other carbon-containing materials including mixed solid waste [12].

Plasma Gasification	Incineration
Occurs in the absence or near absence of oxygen, prohibiting combustion.	Excess air is induced to ensure complete combustion.
Gases resulting from degradation of organics are collected and used for production of various forms of energy and/or industrial chemicals.	All potential energy converted to heat.
Products of degradation largely converted to inert (non-hazardous) glass-like slag of a volume 6% to 15% of the original solids volume.	Combustion results in ash (as much as 30% of original solids volume) that must often be treated as hazardous waste
Emissions substantially lower than those resulting from incineration.	Far greater emissions of GHG and other pollutants than with thermal gasification systems.

Table 5b Differences Between Plasma Gasification and Incineration

The system will also handle such materials as steel beams and rebar; copper piping; steel, aluminum, and copper wire; and even concrete, stone, bricks, although it makes more sense from energy, environmental, and economic perspectives to remove such materials from the waste stream prior to processing [12], [13]Thomas 2007, [4]Dodge 2009). Plasma gasification will also handle treated wood and even contaminated soils – both a problem currently for both landfill and incineration operations.

4.1 EMISSIONS

An authoritative source of gasification products data [14] for plants worldwide is a 2009 University of California report that includes summaries of test results for plasma arc facilities that process circuit boards, medical waste, and MSW. Plasma

Gasification emission products measured included particulate matter, NOx, SOx, hydrochloric acid, and trace amounts of mercury and dioxins/furans; in all cases emissions were well below applicable standards for the regions involved (see Tables 6-8).

Table 6.EPA Environmental Technology Verification Testing (2000) of InEnTec Plasma Arc Gasification of 10 tpd of Circuit Boards, Richland, Washington

Emissions (mg/N-M3@7%O2)	Measured	USEPA Standard
PM	3.3	20
HCL	6.6	40.6
NOx	74	308
Sox	-	85.7
Hg	0.0002	50
Dioxins/furans* (ng/N-m3)**	0.000013	13

** Dioxins and furans are compounds consisting of benzene rings, oxygen, and chlorine that are considered to be toxic or hazardous.*
*** One ng/N-m3 is one nanogram per normal cubic meter; Normal means at standard temperature and pressure.*

Table 7.EPA Environmental Technology Verification Testing (2000) of InEnTec Plasma Arc Gasification of 10 tpd of Medical Waste, Richland, Washington

Emissions (mg/N-M3@7%O2)	Measured	USEPA Standard
PM	<3.3	20
HCL	2.7	40.6
NOx	162	308
Sox	-	85.7
Hg	0.00067	50
Dioxins/furans* (ng/N-m3)**	0.0067	13

Table 8.Results of Third-Party Demonstration Source Tests (2008-2009) of Plasco Energy Plasma Arc Gasification of 110 tpd of MSW, Ottawa, Canada

Emissions (mg/N-M3@7%O2)	Measured	EC 2000/76 Standard
PM	12.8	14
HCL	3.1	14
NOx	150	281
Sox	26	70
Hg	0.0002	14
Dioxins/furans* (ng/N-m3)**	0.009245	0.14

The Georgia Tech PARF lab conducted several tests [15] using their prototype plasma gasification units. One of the units contained a 100 kW and the other a 240 kW plasma heating system. The plasma gas was mainly air; however, Argon and Hydrogen were tested too. 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 show that significant weight and volume reductions of MSW were achieved after plasma processing [15]. In addition:

1. 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, Tables 9 and 10.
2. Output Gas Composition: Table-11 shows the output syngas compositions for experiment without soil and with soil respectively in parts per million:

Toxicity Leaching Tests Results: Tables 9 and 10 show the results of standard toxicity characteristics leaching procedure for experiment without soil and experiment with soil respectively.

TABLE 9.TOXICITY LEACHING RESULTS FOR EXPERIMENT (WITHOUT SOIL) [15]

Heavy Metal	Permissible Concentration (mg/l)	Measured Concentration (mg/l)
Arsenic	5.0	BDL (0.1)
Barium	100.0	0.47
Cadmium	1.0	BDL (0.1)
Chromium	5.0	BDL (0.1)
Lead	5.0	BDL (0.1)
Mercury	0.2	BDL (0.01)
Selenium	1.0	BDL (0.2)
Silver	5.0	BDL (0.1)

BDL = Below Detectable Level

TABLE 10.TOXICITY LEACHING RESULTS FOR (WITH SOIL)

Heavy Metal	Permissible Concentration (mg/l)	Measured Concentration (mg/l)
Arsenic	5.0	BDL (0.1)
Barium	100.0	BDL (0.1)
Cadmium	1.0	BDL (0.1)
Chromium	5.0	BDL (0.1)
Lead	5.0	BDL (0.1)
Mercury	0.2	BDL (0.01)
Selenium	1.0	BDL (0.2)
Silver	5.0	BDL (0.1)

BDL = Below Detectable Level

Table 11 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.

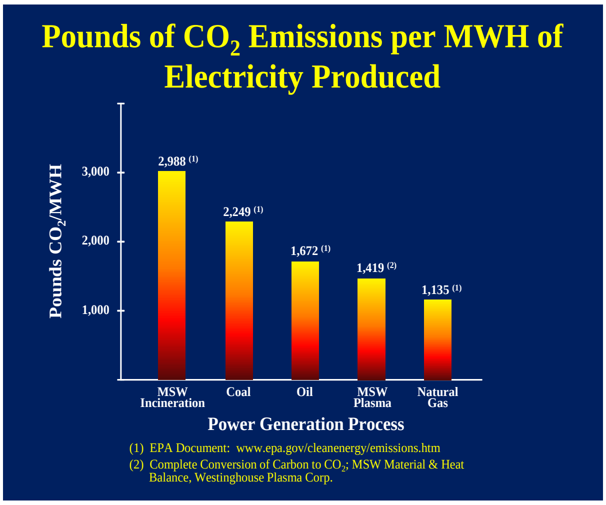

Fig. 4: Pounds of CO2 Emissions per MWH of Electricity Produced

The rate of Carbon dioxide emission [16] per MWH of electricity produced from different processes is shown in Fig.4

Each plasma gasification application will have a differing environmental profile, [5]but in general terms a plasma gasification facility will have very low emissions of NOx, SOx, dioxins and furans. In summary, when compared to conventional incineration or traditional gasification technologies, the WPC Plasma Gasification technology and its plasma torch systems offer the following benefits listed in table 4:

4.2 Waste Destruction and Power Generation Requirements

There is an emerging global [17],[10]consensus to develop local level solutions and community participation for better MSW management. Emphasis has been given to citizens' awareness and involvement for better [18]waste management. A number of studies were carried out in the past to compare different methods of waste disposal and processing for different places. Study for the Netherlands[19]concluded that composting was the best option of waste management. Study for the United Kingdom concluded that refused derived fuel [20]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 studyaims to establish the best feasible method which will solve the twin problems of waste and power generationin Nigeria by taking various factors in consideration.

The suitability of a particular technology for solving waste and power problems will depend on a number of factors which includes techno-economic viability, fuel availability, environmental factors, sustainability [21] and geophysical background of the location. The Plasma Gasification [22] Technology seems to be a realistic solution for waste destruction and power generation in Nigeria. It is a disposal process,that can get rid of almost any kind of waste by eliminating existing landfills, open dumps, and produce clean power for the national grid.

4.3 Land requirement

The land and transportation facilities are basic requirement for waste destruction/power generation. As per the provisions of Municipal Solid Waste (Management and Handling) Rules, 2000, the landfill site shall be large enoughto last for 20-25 years[10]. 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), [5]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 2.02 Hectares (5Acres) of land. Increasing the capacityof the plant to 3000 M.T. per day would increase land requirement to about 4.04 Hectares (10 Acres).

4.4 Sustainability

The sustainability of any project depends up on the capital cost, running & maintenance cost, availability of raw materials (feedstock for the plant) 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,[16] hence, reducing the payback period.Nedcorp group plasma gasification system using Westinghouse Plasma Corporation plasma touches [5] uses 2 to 5% of energy input to produce 80% of energy output. Typical plasma gasification for waste to energy plant with a feedstock of 3,000 MT of MSWper day isestimated tocost over $400 million for installation and will generate about 120 MW of electricity [15]. Estimation for a 2,000 MT of MSW per day [23] is about $250 million. Most of the Plasma Gasification Plants require 120 Kwh of energy for un-segregated per ton of MSW and 816 kwh electricity is generated from the process. It is also projected [15]that each ton of MSW has the potential to produce 900 kWh. The same plant can produce 1,200 kWh for each ton of MSW if it is equipped with cogeneration auxiliaries i.e. steam turbine and gas turbine in an integrated gasification combine circle (IGCC). This implies that similar to any other new technology, the cost will decrease significantly after the commencement of mass production.

5.0 Results and discussion

The problems of Waste and Power shortages in Nigeria can be resolved by a single process of plasma gasification of municipal solid waste. The feasibility conducted [1] showed that power demand exceeds supply, and only a maximum of about 3,653MW of electricity is available for a population of over 160 million. It is also reported [24] that over 5000MT/day of MSW is available in Abuja, a City in Nigeria. The solution of these twin problems seems to be available in Plasma Arc Gasification of MSW.

The Plasma Gasification Process of Municipal Solid Waste is a proven technology for waste to energy production [15]. The vitrified glass generated as residue from Plasma Gasification Process is alsoenvironmentally safe for toxicity leaching. The reaction processes inPlasma Arc Gasification produce mainly syngas (Hydrogen and Carbon monoxide). WPCPlasma 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 NOx, SOx, 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 limits [12], the process is environmentally safe in terms of rate of Carbon dioxide emission [16]per MWH of electricity produced in comparison to different processes as depicted in Fig.4. The land requirement for management of Municipal Solid Waste through landfillswould be around 1000ha for 5000MT/day as per rule 2000[10]. However, processing of 3000MT/day by plasma gasification process will require only 4.02ha of land, [5]. There is a significant reduction in the space required for MSW managementand power generation using plasma arc gasification process.The Plasma Gasification Processing (PGP) plants will generate over 320MW of electricity when 5000MT/day is processed[5]; [24]and this will be added to the national grid. This power will be produced in just one city in Nigeria. Extension of this process to the 36 states in Nigeria will on average produce over 10,000MW which could reduce the power shortages and clean up the environment in Nigeria.

Developing countries, though poor should develop area-specific solutions to their problems [25]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 [22] of disposing MSW. Municipal solid waste is considered as a 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 purports to be an economic and abundant source of energy, and a reliable source of power. Looking ahead to many applications of Plasma Gasification Process, the profit potential of plasma conversion [23] is tremendous.

The plasma gasification process of MSW has all the merits of adoption for power generation, 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, environmental friendly and regionally available must be the best choice. Other challenges such as, skepticism about the technology, lack of historical data, a mislabeling of plasma gasification technology as another type of incineration and a lack of government sponsored development and pilot projects, have contributed to the lack of progress in development and utilization of this technology, [15].

Plasma Arc Gasification for power generation from abundant waste in Nigeria is viable and sustainable, however, the most important factor is the will of the people to change the existing system and develop somethingnew and probably better. The government should take the required initiatives to make this process successful, although financialconstraints will always be a factor in the system, the government can make aformal and sincere commitment for this technology which is proven to generate a clean and sustainable power for the national grid.

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