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Sustainable Power Generation by Plasma Physics

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Abstract: **-** One of the greatest challenges of developing countries today is electric power generation. The demand for Electric power is far above generation and distribution capacities. For instance, only about 4000MW of electricity is available for nearly 170 million people in Nigeria today. On the other hand, the cities are littered with municipal solid wastes in open dumps which are dangerous to health and environment. Sustainable and successful waste management should be safe, effective, environmentally friendly and economically viable. Application of plasma Physics in waste to energy can be one of the novel ways of sustainable power generation. In plasma gasifying cupola, the organic waste materials are gasified to generate a syngas and steam which can be used to generate electricity by integrated gasification combine circle. The inorganic part of the waste is vitrified to a benign residue used for construction. This paper describes the physics and technology involved, reviews the power situation in Nigeria and the benefits of implementation of this technology in waste to electric power generation. This might be an environmentally Safe and sustainable economic solution for waste management and alternative clean power generation.

***Keywords:* -** *Plasma physics, gasification, waste to energy, syngas, power generation.*

I. INTRODUCTION

Plasma physics and associated technologies could address power shortages in fast growing economies, especially in developing countries such as Nigeria. 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 167 million people. With a GDP of US$196 billion in 2010, US$230 billion in 2011 and an average annual growth rate of 7%, [1] 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.

1.1 Power Demand in Nigeria

As at 2004, Total installed generation capacity was 6,102MW, 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 mw. 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.

1.2 Plasma Physics

Plasma is the fourth state of matter. About 99% of the matter in the universe is in the plasma state. Plasmas exist in astronomical bodies with temperatures in millions of degrees. Plasma is a gas in which an important fraction of the atoms is *ionized*, so that the electrons and ions are separately free. This occurs when the temperature is hot enough to overcome ionization threshold energy, about 13.6eV.

Balance between collisional ionization and recombination:

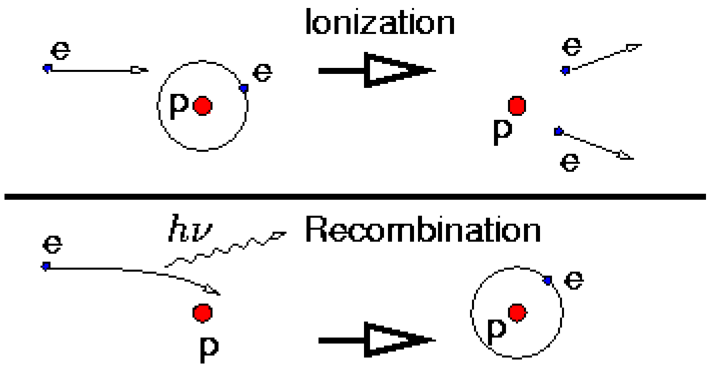

Figure 1. Ionization and Recombination

Recombination is much less probable.

Plasmas are said to be quasi neutral as Electrostatic force >> Kinetic Pressure Force.
This is one aspect of the fact that, because of being ionized, plasmas exhibit all sorts of collective behavior, different from neutral gases, mediated by the long distance electromagnetic forces E, B. In plasma, the Debye length,

$$\lambda_D \equiv \left(\frac{\epsilon_0 T_e}{e^2 n_\infty} \right)^{1/2}$$

<< Size of the plasma

Where the electron temperature is T_e as the particle density, n_∞ is very large in the plasma sheath.
Usually we include as part of the *definition* of a plasma that λ_D << the size of plasma. This ensures that collective effects, quasi-neutrality etc. are important. If N_D = Number of particles in the `Debye Sphere, then for plasmas, $N_D >> 1$ (Collective effects dominate over collisions)
Thus, Plasma is an *ionized* gas in which collective effects dominate over collisions.

$$[\ \lambda_D << \text{size of plasma} \quad , \quad N_D >> 1\ ]$$

We have established two conditions under which an ionized gas can be plasma. A third condition has to do with oscillations [2]. If ω is the frequency of oscillation and τ is the mean period between oscillations, then $\omega\tau > 1$ for the gas to behave like plasma rather than a natural gas. Therefore, three conditions an ionized gas must satisfy to be called plasma are: λ_D << size of plasma, $N_D >> 1$, and $\omega\tau > 1$. The word plasma comes from Greek word: πλά σμα, -ατος , τό which implies fabricated or molded substance.

Apart from naturally occurring plasmas in the universe, artificial Plasma may be created in the laboratory by a variety of ways, including passing a gas, which serves as a dielectric, between objects with large electrical potential differences, or by exposing gases to high temperatures, as in the case of arc welding or graphite electrode torches. The potential difference and subsequent electric field causes ionization of the gas and electrons are pulled toward the anode while the nucleus 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°C. The ability to increase the temperature of the process gas to temperatures 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. The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields[3].

1.3 Plasma Physics Applied to Gasification

Plasma technology was developed and employed in the metal industry during the late 1800s to provide extremely high heat. 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. Utilizing the same plasma physics, scientists who previously worked for NASA, have refined and improved the plasma arc technology in efficiency, cost, and wider user applications; the lead NASA scientist, Dr. S.L. Camacho used this technology to convert waste to energy [4]. The gaseous emission to the atmosphere were 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 and landfills are becoming outmoded. The harmful attributes of landfills to environment were predicted [5]. They suggested that Sustainable and successful waste management should be safe, effective, and environmentally friendly.

Plasma technology adaptation to large-scale solid waste disposal via gasification and recovery of energy from the generated gas is relatively new. As noted by [6], "Plasma gasification of municipal 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.

1.4 Plasma Gasification Technology

As mentioned above, artificial Plasma may be created by 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 [7]. 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 byproducts consisting of glass-like substances used as raw materials for construction, and also re-useable metals. Syngas is a mixture of hydrogen and carbon monoxide 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 also used to drive a second turbine to generate additional electricity – The integrated gasification combine circle (IGCC) thus produce adequate electricity, part of which is used for the plant's load and the rest of the power generated is 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.

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 [7]. 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:

- It 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.

II. WASTES TO POWER GENERATION MATERIALS AND METHODS

Plasma physics applied to gasification represents a clean and efficient option to manage waste in an environmentally responsible manner. The plasma gasification technology is ideally suited to process wastes 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 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 dumps uncontrolled 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, pollution of ground water, spread of infectious diseases, highly toxic smoke from continuously smoldering fires, foul odors from decomposing refuse and emission of greenhouse methane gas. Several million tons of wastes have been deposited in open dumpsites across the country over the years. A new technology such as Plasma Physics applied to Gasification of MSW may prove to be an environmentally friendly and sustainable solution for wastes disposal and power generation.

2.1 Gasification Process

The gasification reaction for MSW is generally written as follows [5]:

$CH_xO_y + wH_2O + mO_2 + 3.76mN_2 \rightarrow aH_2 + bCO + cCO_2 + dH_2O + eCH_4 + fN_2 + gC$

Where waste material is described by its global analysis, CHxOy), 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 H_2 and CO generated during the gasification process can be a fuel source for power generation.

2.2 Plasma Gasification of Municipal Solid Waste (MSW)

Plasma gasification is an efficient and environmentally responsible form of thermal treatment [8] 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 [9], [7],[10] which uses plasma heat in a vertical shaft cupola adopted from the foundry industry. The plasma gasification process is illustrated in Fig. 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 gasifying vessel to gasify the waste. The power of plasma gasification makes it environmentally clean technique. Plasma Gasification Plant projects [11] are being developed by many gas plasma companies, with real benefits obtained from this technology.

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 wastes, breaks down organic compounds and dries the wastes at the top of the "gasifier". As the waste moves downward through the "gasifying" 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.

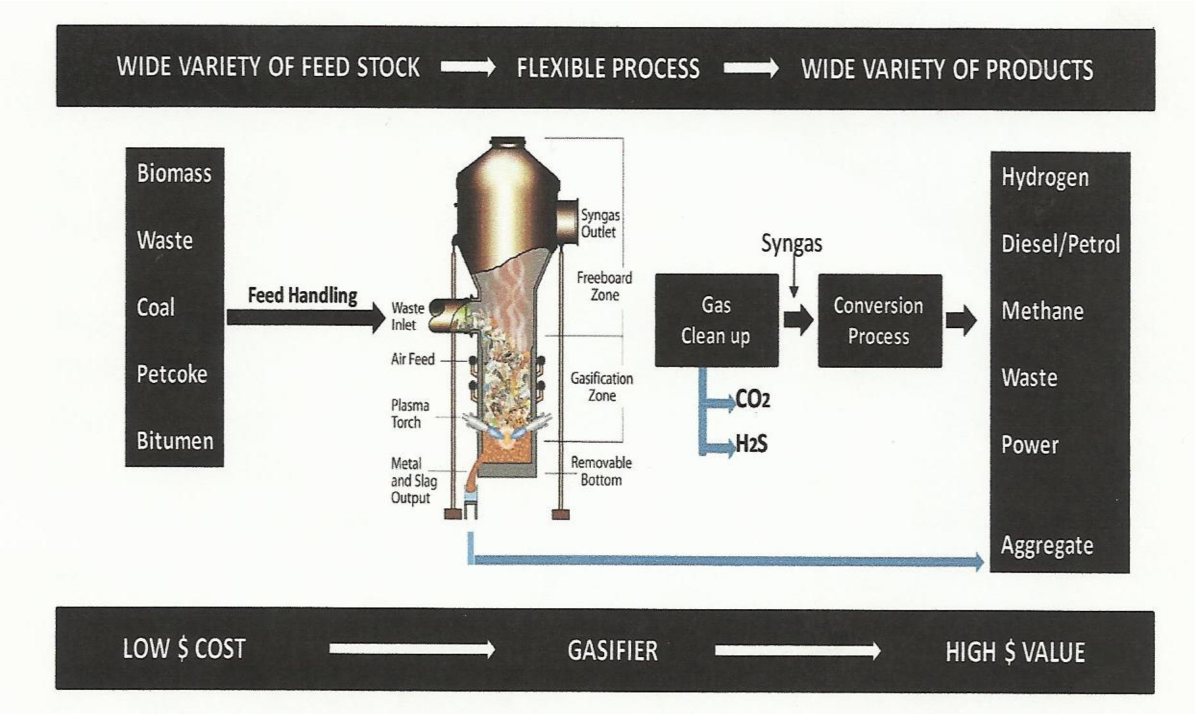

Fig. 2.0 Plasma gasification process

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

For Power generation process, 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. This is the process of integrated gasification combined cycle power generation.

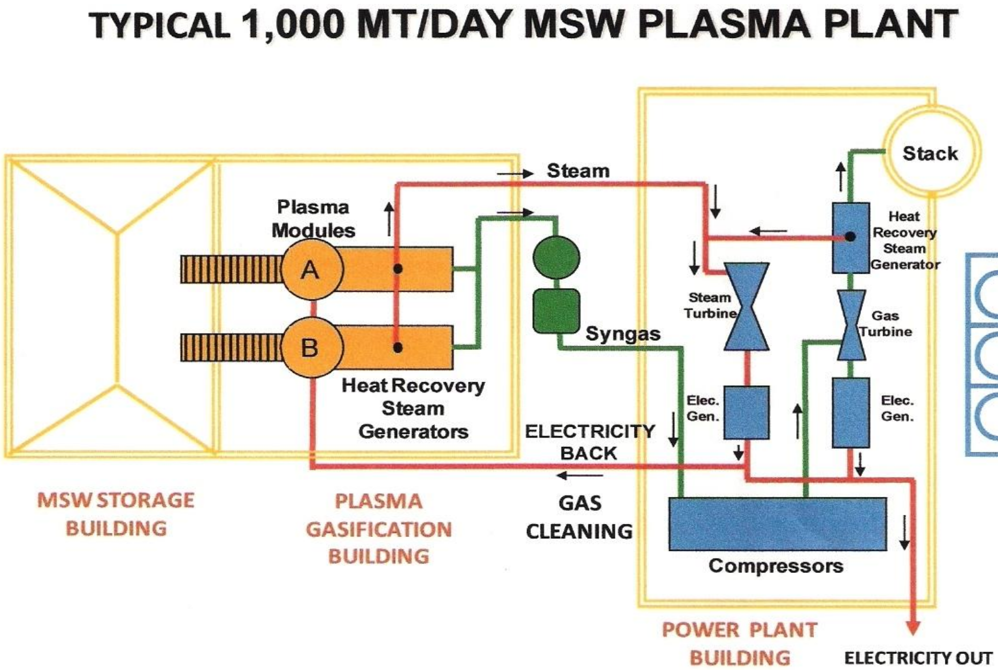

Fig.3 Typical 1000MT MSW plasma plant using ICCG for power generation

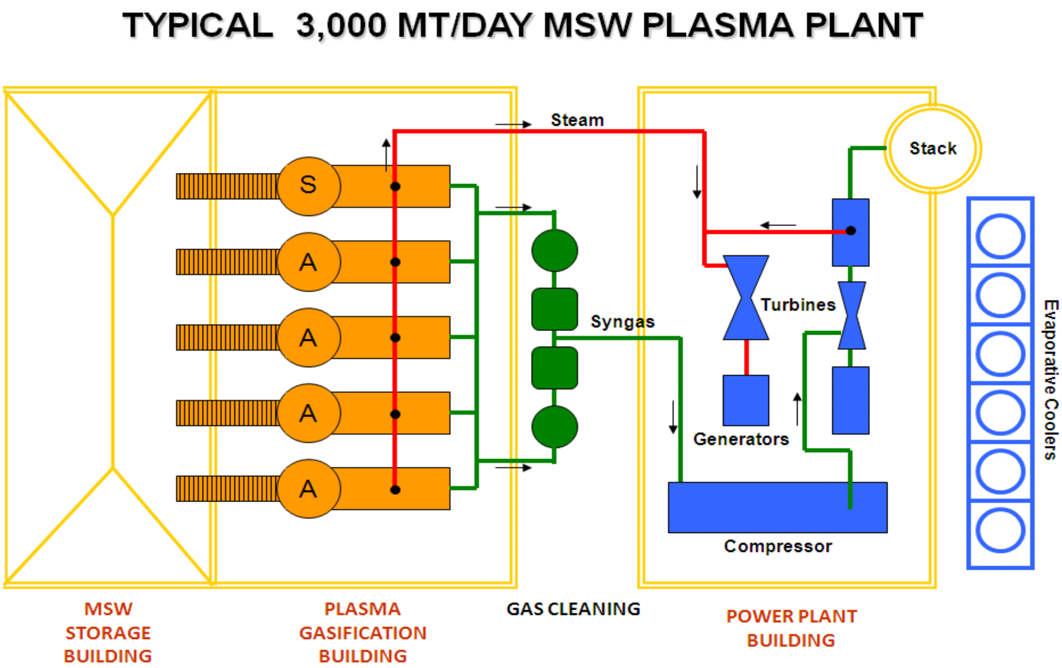

Figure 4: Plasma plant facility using IGCC for power generation

2.3.1 Scalability of the Plasma Power System

The diagrams (Fig.3 and Fig.4) illustrate typical plant layout configurations for plants having process capacities of 1000 MT per day and 3000 MT per day Municipal Solid Waste and demonstrate the relative ease by which plants can be expanded to meet increasing loadings through the use of standardized process modules with capacities of 500 and 750 MT/day. Note that in these examples, a standby module has been included in the design to assure that processing capacity can be maintained during periods of scheduled maintenance.

It should also be noted that a similar configuration in Fig.4 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.

2.3.2 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 1 below.

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.

Table 1 Economies of Scale in Combined Cycle and Simple Cycle Plasma Gasification

		Conventional Steam Turbines					Combined Cycle (IGCC)				
Plant Capacity MT/day	Heat Input (MWht	Gross Mwe	Net Mwe	Plant Load	MWh / MT MSW	Overall Efficiency %	Gross Mwe	Net Mwe	Plant Load	MWh/ MT MSW	Overall Efficiency %
500	83.3	19.7	16.1	3.63	0.77	19.3	33.7	26.7	6.93	1.28	32.1
2500	416.4	122.0	103.7	18.26	1.00	24.9	186.9	152.1	34.76	1.46	36.5
5000	832.7	259.6	223.1	36.52	107	26.8	393.4	323.8	69.52	1.55	38.9

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 [7]. 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 from incineration (Table 2).

Table 2 Plasma Gasification and Incineration

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.

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].

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], [6]. Plasma gasification will also handle treated wood and even contaminated soils – both a problem currently for both landfill and incineration operations.

2.4.1 Waste Management and Power Generation Requirements

The rate of Carbon dioxide emission [14], [10] per MWH of electricity produced from different processes is very low for plasma gasification of MSW process.

Low Dioxin/Furan emissions:

– Less than 0.01 NG/NM³ of Dioxins/Furans
– Sulfur reports as Hydrogen Sulfide (H2S) easier to clean than Sox
– Tars are cracked prior to leaving the Gasifier.

"One technology which potentially can use various types of waste, produce electricity and hydrogen without emitting dioxin, furan and mercury, is plasma arc technology.
Municipalities can install a plasma arc facility which will eliminate land filling ..."
- EPA

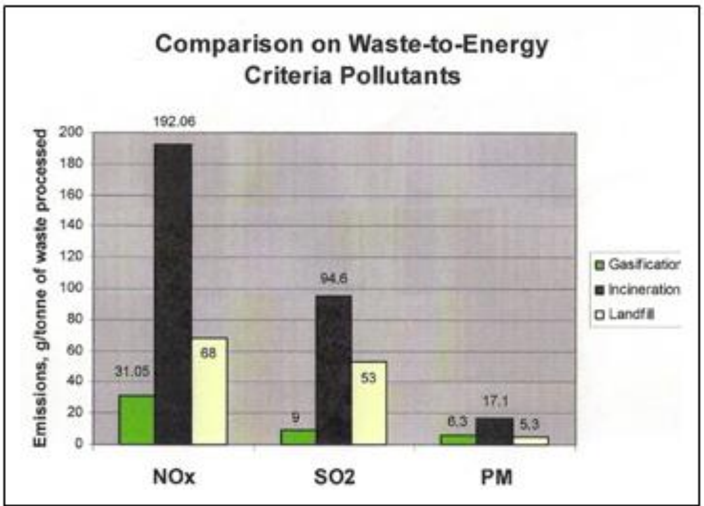

Figure 5. Comparison of emissions on waste to power generation from Gasification. Incineration and Landfill

Carbon Dioxide Emissions

Plasma gasification WTE facility avoids:
1. The release of methane that otherwise would be emitted when trash decomposes in landfills

2. The displacement of CO_2 that would have been emitted had the electricity been generated from fossil fuels such as coal.

This sophisticated waste destruction and electric power generating system operates on the principle of environment friendly waste destruction and sustainable generation of renewable energy.

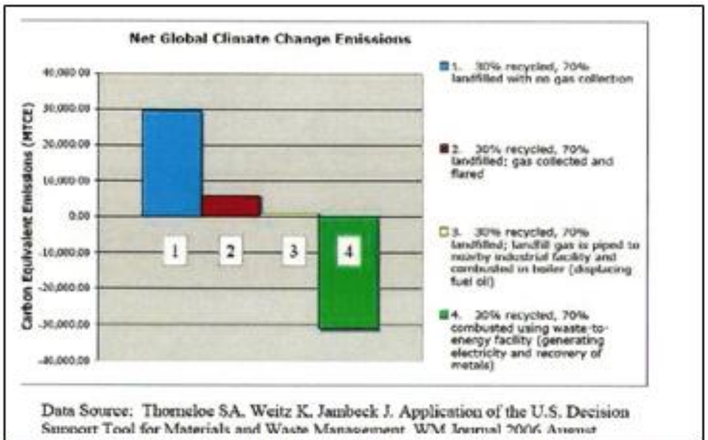

Figure 6. Net climate change emissions are negative compared to other waste management options

Each plasma gasification application will have a differing environmental profile [7], but in general terms a plasma gasification facility will have very low emissions of NOx, SOx, dioxins and furans.

There is an emerging global ([15], [16] consensus to develop local level solutions and community participation for better MSW management. Emphasis has been given to citizens' awareness and involvement for better [17] 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 [18] concluded that composting was the best option of waste management. Study for the United Kingdom concluded that refused derived fuel [19] 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 paper aims to establish that plasma physics applied to gasification of MSW will not only lead to proper waste destruction but enhance alternative power generation.
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 [20]

and geophysical background of the location. The Plasma Gasification [21], [10] technology seems to be a realistic solution for waste destruction and power generation. 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.

2.4.2 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 enough to last for 20-25 years [9]. 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),[7] , [10] 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 (5 Acres) of land. Increasing the capacity of the plant to 3000 M.T. per day would increase land requirement to about 4.04 Hectares (10 Acres).

2.4.3 Sustainability

The sustainability of any project depends up on the capital cost, running & maintenance cost, availability of raw materials (feedstock for the plant) and return on investment. 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, [14] hence, reducing the payback period and increase return on investment. Nedcorp group plasma gasification system using Westinghouse Plasma Corporation plasma touches [7] 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 MSW per day is estimated to cost over $400 million for installation and will generate about 120 MW of electricity [16]. Estimation for a 2,000 MT of MSW per day [22] is about $250 million. Most of the Plasma Gasification Plants require 120 Kwh of energy to process each ton of MSW and 816 kwh electricity is generated from the process. It is also projected [16] 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.

III. RESULTS AND DISCUSSION

The problems of Waste and Power shortages in the world can be resolved by a single process of plasma physics applied to gasification of municipal solid waste. The feasibility conducted[1] showed that power demand exceeds supply, and only a maximum of about 3,300MW of electricity is available at given time for a population of over 165 million in Nigeria. The solution of these twin problems seem to lie in the physics of Plasma Gasification. The Plasma Gasification Process of Municipal Solid Waste is a proven technology for waste to energy production [16]. The reaction processes in Plasma Gasification produce mainly syngas (Hydrogen and Carbon monoxide). The syngas is efficient in power generation using integrated gasification combined circle (ICCG) plasma process. 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 per MWH of electricity produced in comparison to different processes as depicted in Fig.6. The land requirement for management of Municipal Solid Waste through landfills would be around 600ha for 3000MT/day as per rule 2000. However, processing of 3000MT/day by plasma gasification process for power generation will require only 4ha of land. There is a significant reduction in the space required for MSW and power generation using plasma gasification process. The Plasma Gasification Processing plants will generate over 320MW of electricity when 5000MT/day is processed, Table 1 and this will be added to the national grid.

IV. CONCLUSION

Developing countries, should seek area-specific solutions to their problems [23] 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 [21] 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 physics applied to gasification is an economic and sustainable source of energy, and a reliable source of power generation in integrated gasification combined cycle (IGCC). There are many applications of Plasma Gasification Process and the profit potential of plasma conversion [22] is tremendous.

The plasma physics applied to gasification p 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 and power that are sustainable, environmentally 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 have contributed to the lack of progress in development and utilization of this technology.

Plasma Physics applied to Gasification of MSW for power generation from abundant waste is viable and sustainable. The most important factor is the will of governments and people to change the existing system and develop something new and probably better. It is the author's considered opinion that scientists, engineers and governments should take the required initiatives to develop this technology for alternative power generation to address power shortages and reduce the use of fossils.

V. ACKNOWLEDGEMENT

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