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# MUNICIPAL SOLID WASTE MANAGEMENT OPTIONS

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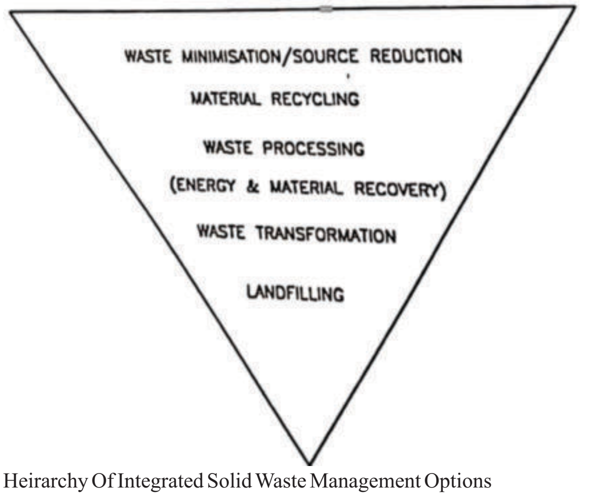
**ABSTRACT** Current thinking on the best methods to deal with waste is centered on already accepted "hierarchy of waste management' (arrangement in order of rank)which gives a priority listing of the waste management options available. The hierarchy gives important general guidelines on the relative desirability of the different management options. 1he hierarchy usually adopted is (a) waste minimization/reduction at source, (B) recycling, (C) waste processing (with recovery of resources i.c. materials (products) and energy), (d) waste transformations (without recovery of resources) and (C) disposal on land(land filling).

The highest rank of the ISWM hierarchy is waste minimization or reduction at source, which involves reducing amount (and/or toxicity) of the wastes produced. Reduction at source is first in the hierarchy because it is the most effective way to reduce the quantity of waste, the cost associated with its handling and its environmental impacts. The second highest rank in the hierarchy is recycling, which involves (a)the separation and sorting of waste materials; (b) the preparation of these materials for reuse or reprocessing; and (c) the reuse and reprocessing of these materials. Recycling is an important factor which helps to reduce the demand on resources and the amount of waste requiring disposal by land filling. The third rank in the ISWM hierarchy is waste processing which involves alteration of wastes to recover conversion products (e.g., compost) and energy. The processing of waste materials usually results in the reduced use of landfill. Capacity. Transformation of waste, without recovery of products or energy, may have to be undertaken to reduce waste volume (e.g. shredding and bailing) or to reduce Toxicity. This is usually ranked fourth in the ISWM hierarchy. Ultimately, something must be done with (a) the solid wastes that cannot be recycled and are of no further use; (b) the residual matter remaining after solid wastes have been pre-sorted at a materials recovery facility; and (c) the residual matter remaining after the recovery of conversion products or energy. Land filling is the fifth rank of the ISWM hierarchy and involves the controlled disposal of wastes on or in the earth's mantle. It is by far the most common method of ultimate disposal for waste residuals. Land filling is the lowest rank in the ISWM hierarchy because it represents the least desirable means of dealing with society's wastes. While most of the focus in waste management in on municipal solid waste management, it is important to note that MSW is but a small fraction of the total amount of waste generated in the India. The municipal Solid Waste Management Rules 2016 which is the major rules that governs Solid Waste Management in India.




Heirarchy Of Integrated Solid Waste Management Options

**KEYWORDS :**

## INTRODUCTION

Rapid modernization and urbanization has lead to change the lifestyle of urban population thus increasing the waste generation. Due to this there is constant disposal of garbage in the dumping sites this has flooded the sites and cannot further bear the burden. This also creates illegal dumping of waste at different location. This contributes spreading of pollution, foul odour, communicable diseases etc. waste can be treated as resource and it can be used for production of energy and compost.

The different technologies available for SWM. It is focused on the emerging SWM technologies which could be applicable for the Indian conditions and which could be practiced on the regular basis. The technology option available for processing the MSW are based on either bio conversion or thermal conversion. The bio-conversion process is applicable to the organic fraction of wastes, to form compost or to generate biogas such as methane (waste to energy) and residual sludge (manure). Various technologies are available for composting such as aerobic, anaerobic and vermin-composting. The thermal conversion technologies are incineration with or without heat recovery, pyrolysis and gasification, plasma-pyrolysis and polarization or production of Refuse Derived Fuel (RDF).

A brief account of these technologies is essential for evaluating their efficiency, applicability and impacts. In many cases, municipal waste are not well managed in developing countries, as cities and municipalities cannot cope with the accelerated pace of waste production. The waste collection rates are often lower than 70% which is equivalent to the conditions in low-income countries. At this location, most of the waste is disposed off into open dumping sites without any further treatment of processing. The two leading innovative mechanisms of waste disposal being adopted in India including composting (aerobic composting and vermin-composting) and waste-to-energy (WTE) (incineration, pelletisation, biomethanation) WTE projects for disposal of MSW are a relatively new concept in India. Although these have been tried and tested in developed countries with positive results.

The various technologies available like Composting, Anaerobic Digestion, Thermal Treatment (incineration, and Landfill, the best technology is suggested or based on current assessment (waste characterization) for this city.

### Municipal Solid Waste Treatment Technologies And Their Options

The biological as thermal treatment of MSW on result in recovery of useful product such as compost or energy. The biological treatment involves using micro-organism to decompose the bio degradable components of waste namely aerobic processes and anaerobic processes. In the anaerobic process the utilizable product is methane gas (for energy recovery) a majority of the biological treatment process adopted worldwide aerobic composting the use of anaerobic treatment has been more limited. The thermal treatment involves conversion of waste into gases, liquid and solid conversion products with concurrent on subsequent release of heat energy. Three types of system can be adopted namely combustion system incinerators, Thermal processing with excess amount of air. Pyrolysis systems thermal processing in complete absence of oxygen (low temperature).Gasification system : thermal processing with less amount of air (High Temperature). The combustion systems in the most widely adopted thermal treatment process worldwide for MSW. Though pyrolysis in a widely use industrial process the pyrolysis of municipal solid waste has not been very successful. Similarly successful results with mass fired, gasifires have not been archived. New biological and chemical process which are being developed for resource recovery from MSW are (a) fluidized bed bioreactors (b) hydrolysis processes to recover organic acids and chemical process to recover oil and gas cellulose. At the end of all sorting process, biological processes and thermal processes the non utilizable waste has to be disposed off an land. Prior to their disposal waste may need to be subjected to transformation by mechanical treatment thermal treatment, other method to make it suitable for land filling.

**Incineration / Combustion**

Incineration is the process of control and complete combustion, for burning solid wastes. It leads to energy recovery and destruction of toxic wastes, for example, waste from hospitals. The temperature in the incinerators varies between 980 and 2000C. One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustible solid waste by 80-90%. In some newer incinerators designed to operate at temperatures high enough to produce a molten material, it may be possible to reduce the volume to about 5% or even less. Unfortunately, in India cities, incineration is not very much practiced. This may be due to the high organic material (40-60%), high moisture content (40-60%), high inert content (30-50%) and low calorific value content (800-1100 kcal/kg) in MSW. The first large-scale MSW incineration plant was constructed at Timarpur, New Delhi in 1987 with a capacity of 300 tons/day and a cost of Rs. 250 million (US$ 5.7 million) by Miljotecknik volunteer, Denmark. The plant was out of operation after 6 month and the Municipal Corporation of Delhi was forced to shut down the plant due to its poor performance. Another incineration plant was constructed at BARC, Trombay (near Mumbai) for burning only the institutional waste, which includes mostly paper and it is working as of this writing. In many cities, common biomedical waste facilities are used for burning hospital waste successfully.

**Pyrolysis**

MSW is initially shredded, screened and separated from incombustible matter before using in Pyrolysis process. Pyrolysis is a thermal process where organic materials present in the waste are broken down under pressure and at temperatures greater than 925°F in the absence of oxygen to become gas comprising smaller molecules (Syngas). Along with syngas, char and oil are also produced. The gases produced comprise carbon monoxide (25%), hydrogen and hydrocarbons (15%) and carbon dioxide and nitrogen (60%). Then, syngas is cleared and burned in internal combustion (IC) engine generator sets or turbines to produce electricity. The syngas produced can be utilized in boilers, gas turbines, or internal-combustion engines to generate electricity or be further processed into organic chemicals. Thermal cracking and condensation reactions produce gaseous, liquid and solid fractions. Three major component fractions resulting from Pyrolysis are:

- Gas Stream - Syngas comprising of $H_2$, $CH_4$, CO,
- Tar and/or oil stream - liquid at room temperature containing chemicals such as acetic acid, acetone and methanol.
- A char consists of almost pure Carbon plus any inert material that may have entered the process.

**Digestion (Anaerobic and Aerobic)**

Digestion is the reduction of organic waste materials through microbial decomposition. It is biological process of digestion which may be aerobic or anaerobic, depending on whether air (oxygen) is introduced into the process or not. *Anaerobic digestion* is a biological process by which microorganisms digest organic material in the absence of oxygen, producing a solid byproduct (dig estate) and a gas (biogas). Anaerobic digestion has been used extensively to stabilize sewage sludge, and has been adapted more recently to process the organic fraction of MSW. The biogas produced from anaerobic digestion is primarily methane and carbon dioxide. Biogas is commonly burned in an internal combustion engine to generate electricity. Biogas also has other potential end uses. For example, biogas can be scrubbed of carbon dioxide, hydrogen sulfide and water to obtain usable methane, which can be compressed and used as an alternative fuel in light- and heavy-duty vehicles. Digested material may be used as a soil conditioner, or compost, after a period of aerobic stabilization.

Biogas is a type of digestion process and it is applicable only for biodegradable component of waste.
Hence segregation is optimum importance for this technology to function efficiently.

The anaerobic digestion process may be either "wet" or "dry", depending on the percent solids in the reactor. The process temperature may also be controlled in order to promote the growth of a specific population of microorganisms. Mesophilic anaerobic digestion occurs at temperatures of approximately 35°C (95°F). Thermophilic anaerobic digestion occurs at temperatures of approximately 55°C (131°F). The wet anaerobic digestion process starts with the organic fraction of MSW, which is mixed with water and pulped. The pulp is fed into a reactor vessel, where optimal heat and moisture conditions are promoted to enhance microbial development and decomposition. The process may be conducted in a single stage or two-stage reactor vessel. Some of the technologies used a dry anaerobic digestion process in which no added water is utilized. For dry anaerobic digestion, the incoming shredded organic solid waste is "inoculated" with previously digested material prior to introduction into the reactor vessel. Material in the digester has a retention time of 15 to 17 days, and moves through the digester in a plug flow manner

In the aerobic digestion process, the organic fraction of MSW is metabolized by microorganisms in the presence of oxygen. During the process, temperature and pH increase, carbon dioxide and water are liberated (reducing the mass of material), and pathogens are destroyed. The digested material may be used as a soil amendment or fertilizer (i.e. compost). Unlike anaerobic digestion, no methane gas is produced in the aerobic digestion process.

**Anaerobic digestion (Biomethanation)**

If the organic waste is buried in pits under partially anaerobic conditions, it will be acted upon by anaerobic microorganisms with the release of methane and carbon dioxide; the organic residue left is good manure. This process is slower than aerobic composting and occurs in fact and has been commercialized. Anaerobic digestion leads to energy recovery through biogas generation. The biogas, which has 55-60% methane, can be used directly as a fuel or for power generation. It is estimated that by controlled anaerobic digestion, 1 t of MSW produces 2-4 times as much methane in 3 weeks in comparison to what 1 tons of waste in landfill will produce in 6-7 years (Ahsan, 1999). In India, Western Paques have tested the anaerobic digestion process to produce methane gas. The results of the pilot plant show that 150 tons/day of MSW produce 14,000 $m^3$ of biogas with a methane content of 55-65%, which can generate 1.2 MW of power. The government is looking forward to biomethanation technology as a secondary source of energy by utilizing industrial, agricultural and municipal wastes. A great deal of experience with biomethanation systems exists in Delhi, Bangalore, Lucknow and many other cities. There is little experience in the treatment of solid organic waste, except with sewage sludge and animal manure (.e.g., cow dung). Several schemes for biomethanation of MSW, vegetable market and yard wastes, are currently being planned for some cities.

Biomethanation is viable technology for rural areas where animal waste (cow dung) is mixed with MSW to increase its performance efficiency.

The study reveals that in all situations (rural, urban or city, etc.) where space is available, composting or waste to energy is the better option because it prevents the load on municipalities for collection and transport of MSW and then reduces the pressure on the landfills. It also provides a valuable byproduct for agriculture.

**Composting**

Composting is an organic method of producing compost manure by decomposition and stabilization of organic matter. Composting process is commonly used method and results in the production of stable compost product reduced in size (when compared to initial size) and free from odors. Compost is particularly useful as organic manure which contains plant nutrients (nitrogen, phosphorous and potassium) as well as micro nutrients which can be utilized for the growth of plants. composting can be carried out in two ways - aerobically (with the presence of oxygen) or an aerobically (without the presence of oxygen) or vermi-composting or by any other biological mechanism.

Controlling some of the composting influencing factors, natural composting process could be accelerated. These influencing factors also have impact on quality of compost produced. Some of the important factors in the composting process are temperature, C/N ratio, phosphorous, sulphur, moisture, particle size, oxygen flow etc.

Again in composting, segregation is the most important aspect along with proper technical maintenance of the process.

**Land filling**

In many metropolitan cities, open, uncontrolled and poorly managed dumping is commonly practiced, giving rise to serious environmental degradation. More than 90% of MSW in cities and towns are directly disposed of on land in an unsatisfactory manner. Such dumping activity in many coastal towns has led to heavy metals rapidly leaching into the coastal water. In larger towns or cities like Delhi, the availability of land for waste disposal is very limited. In the majority of urban centers, MSW is disposed of by depositing it in low-lying areas outside the city without following the principles of sanitary land filling. Compaction and leveling of waste and final covering by earth are rarely observed practices at most disposal sites, and these low-lying disposal sites are devoid of a leachate collection system or landfill gas monitoring and collection equipment. As no segregation of MSW at the source takes place, all of the wastes including infectious waste from hospitals generally find its way to the disposal site. Quite often, industrial waste is also deposited at the landfill sites meant for domestic waste. Sanitary land filling is an acceptable and recommended method for ultimate disposal of MSW. It is a necessary component of MSWM, since all other options produce some residue that must be disposed of through land filling. However, it appears that land filling would continue to be the most widely adopted practice in India in the coming few years, during which certain improvements will have to be made to ensure the sanitary land filling.

**Table No. 1 Comparative table for solid waste management technologies**

| | Composting | Bio-Methanation | Incineration | Pelletisation | Pyrolysis |
|---|---|---|---|---|---|
| Requirement for segregation | Very high | Very high | Low | High | High |
| Potential for Direct Energy Recovery | No | Yes | Yes | No | Yes |
| Overall efficiency in case of a small set up | High | High | Low | Low | Moderate |
| Efficiency in case of high Moisture | High | High | Moderate | Low | Low |
| Land requirement | High | Low to moderate | Low | Low | Moderate |
| Leachate Pollution | High, if not routed properly | Moderate to high in case effluent is not properly | None | None | None |
| Toxicity | None | None | Moderate | None | None |

**Table No. 2 Influencing Parameters and Constraints of Various MSW Technologies**

| Technologies | Influencing Parameters | Limitations | Benefits |
|---|---|---|---|
| Composting | • Segregation of | • Receiving of | • Reduces volume of organic waste |
| Composting | • organics from MSW.<br>• Quantity of organic matter.<br>• Moisture content<br>• Market demand.<br>• Location of the facility. | • unegregated waste.<br>• No yield consistency (varying composting quality)<br>• Slow Process.<br>• Sound marketing are required.<br>• Sensitive process- requires good segregation and maintenance.<br>• Limited acceptance by the farmers and sometimes even bythe city parks and gardens department. | • fraction of MSW by 50 to 75%.<br>• Stabilizer organic fraction of MSW.<br>• Potential usable product as output.<br>• Potential of co-composting operations with other waste streams.<br>• Reduces organic waste to landfill thereby reducing the production of leachate and gases from landfill.<br>• Highly useful product for crop improvement.<br>• Value additional to waste resource. |
| Biomethanation or Anaerobic Digestion | • Moisture Content.<br>• Organic/Volatile matter.<br>• C/N ratio.<br>• Segregation of Organic waste.<br>• Quantity of organic matter.<br>• Market demand. | • Higher capital costs.<br>• Not suitable for wastes containing less biodegradable matter.<br>• Non-availability of segregated waste in the municipality.<br>• Lack of financial resources with ULB's and municipal corporations.<br>• Requires waste segregation for improving digestion efficiency. | • Completes natural cycle of carbon.<br>• Recovery of energy & production of fully stabilized organic manure.<br>• Control/Reduction of Greenhouse Gas emissions like Methane.<br>• Complete destruction of Pathogens through anaerobic digestion - No transmission of disease through vectors.<br>• Only pre-processing rejects - No post processing rejects.<br>• Reduced burden on Landfills.<br>• Conversion efficiency: 60 to 70%.<br>• Clean combustion, compact burning, high thermal efficiency and good degree of control.<br>• Environment friendly because of firewood. |
| Incineration | • Calorific value<br>• Moisture content<br>• Organic/volatile matter.<br>• Fixed carbon<br>• Total Inerts | • Excessive moisture and inert content in waste affects net energy/recovery.<br>• Auxiliary fuel support may be necessary to sustain combustion;<br>• High capital and O&M costs.<br>• Most wastes which can safely be burned (i.e. vegetation, cardboard paper) may be more useful if | • Achieves maximum volume reduction.<br>• Incineration is a standard hygienic operation compared to open burning.<br>• Heat generated canbe utilized for production of steam/ hot water/electricitym<br>• Less land is required and minimal burden on landfills.<br>• Most suitable for high calorific value waste etc.<br>• Relatively noiseless and odorless.<br>• Thermal energy |

| | | | |
|---|---|---|---|
| | | recovered for mulching and soil improvement.<br>• Residual ash and metal waste require disposal.<br>• Overall efficiency is low for small power stations.<br>• Indian MSW as low calorific value; hence supplementary fuel is required for combustion and hence high fuel costs. | recovery for direct heating or power generation.<br>• Can be located within city limits, reducing cost of waste transportation. |

**Plasma Arc Gasification Process**

The Plasma arc gasification process is the most advanced and efficient technology available. Its name is due to the process of generating plasmas (the so-called "4th state of matter") by ionizing a gas in the rector. The plasma flames generated are essentially lightning bolts, created by high-voltage arcs. Temperatures in this process range from 7,200 to 12,600°F. MSW is generally shredded, then fed into the plasma reactor with sub-stoichiometric volumes of oxygen or air. The syngas produced can be cleaned, and used to make electricity. The solid residue from plasma arc gasification is unique. A glass-like by-p[product, known as vitrified slag, extrudes from the bottom of the rector. An attractive characteristic of this material is that its components do not leach out. The vitrified slag consists of metals and silicate glasses which fuse together into an inert solid. Vitrified slag has more uses than ash from conventional gasification, including as insulation material, flooring tiles, and garden blocks. By utilizing plasma arc technology it is possible to generate 816 kWh per ton of MSW.

**Table No. 3 SUMMARY OF WTE OUTPUT**

| WTE Technology | Operating Temperatures (°F) | Energy Production (kWh/ton MSW) |
|---|---|---|
| Incineration | 1,000 - 2,000 | 544 |
| Pyrolysis | 12,00 - 2,200 | 571 |
| Conventional Gasification | 1,450 - 3,000 | 685 |
| Plasma Arc Gasification | 7,200 - 12,600 | 816 |

**Table No. 4 SUMMARY OF WTE BY-PRODUCTS**

| WTE Technology | By-products |
|---|---|
| Incineration | High pressure steam, ash, exhaust gaes. |
| Pyrolysis | Raw syngas, bio-oil, ash, char, metals. |
| Conventional Gasification | Raw syngas, bio-oil, ash, slag, metals. |
| Plasma Arc Gasification | Raw syngas, inorganic materials, vitrified slag. |

Advantages and Disadvantages of Different Technological Options The main advantages and disadvantages of the different technological options described above are given in Table

**Table No. 5 Advantages And Disadvantages Of Different Technological Options :**

| Advantages | Disadvantages |
|---|---|
| Anaerobic Digestion<br>Energy recovery with production of high grade soil conditioner<br>No power requirement unlike aerobic composting, where sieving and turning of waste pile for supply of oxygen is necessary<br>Enclosed system enables all the gas produced to be collected for use.<br>Controls Green House Gases Emission<br>Free from bad odour, rodent and fly menace, visible pollution and social resistance. | Heat released is less-resulting in lower and less effective destruction of pathogenic organisms than in aerobic composting. However, now thermophilic temperature system are also available to take care of this.<br><br>Unsuitable for wastes countaining less organic matter<br><br>Requires waste segregation for improving digestion efficiency. |
| Modular construction of plant and closed treatment needs less land area.<br><br>Net positive environmental gains.<br><br>Can be done at small-scale | |
| Landfill Gas Recovery<br>Least cost option. | Greatly polluted surface run – off during rainfall. |
| The gas produced can be utilized for power generation or as domestic fuel for direct thermal applications.<br><br>Natural resources are returned to soil and recycled.<br><br>Can convert low lying marshy land to useful areas. | Soil / groundwater acquifers may get contaminated by polluted leachate in the system<br>Inefficient gas recovery process yielding 30-40% of the total gas generation. Balance gas escapes to the atmosphere (significant source of two major Green House gases, carbon dioxide & methane)<br>Large land area requirement<br>Significant transportation costs to faraway landfill sites may upset viability<br><br>Cost of pre treatment to upgrade the gas to pipeline quality and leachate treatment may be significant.<br><br>Spontaneous ignition/explosions due to possible build up of methane concentrations in atmosphere. |
| Incineration<br>Most suitable for high Calorific Value waste, pathological wastes, etc.<br><br>Units with continuous feed and high through-put can be set up.<br><br>Thermal Energy recovery for direct heating or power generation.<br><br>Relatively noiseless and odourless.<br><br>Low land area requirement. | Least suitable for aqueous/ high moisture content/ low Calorific Value and chlorinated waste.<br><br>Excessive moisture and inert content affects net energy recovery; auxiliary fuel support may be required to sustain combustion<br><br>Concern for toxic metals that may concentrate in as, emission of particulates, SOx, NOx, chlorinated compounds, ranging from HCL to Dioxins. |
| Can be located within city limits, reducing the cost of waste transportation. | High Capital and O&M costs.<br>Skilled personnel required for O&M<br>Overall efficiency low for small power stations. |
| Pyrolysis / Gasification<br>Production of fuel gas/ oil, which can be used for a variety of applications<br><br>Compared to incineration, control of atmospheric pollution can be dealt with in a superior way, in techno-economic sense. | Net energy recovery may suffer in case of wastes with excessive moisture.<br>High viscosity of pyrolysis oil may be problematic for its transportation &burning . |

**Land Requirements**

The area of land required for setting up any Waste Processing/ Treatment facility generally depends upon the following factors:

- Total waste processing/treatment capacity, which will govern the overall plant design/size of various sub-systems.
- Waste quality/characteristics, which will determine the need for pre-processing, if required, to match with the plant design.
- Waste treatment technology selected, which will determine the waste fraction destroyed to energy.
- Quantity and quality of reject waste, liquid effluents and air emissions, which will determine the need for disposal/post treatment requirements to meet EPC norms.

As such, the actual land area requirement can be worked out only in the Detailed Project Report for each specific project. However, for initial planning the following figures may be considered for 300 TPD (input capacity) Waste-to-Energy facilities.

| | |
|---|---|
| Incineration/Gasification/Pyrolysis plants | 0.8 hectare* |
| Anaerobic Digestion Plants | 2 hectares* |
| Sanitary Landfills (including Gas-to-Energy recovery) | 36 hectares** |

- Based upon typical installations

For areas away from coast (can be more in coastal areas). This is estimated on the basis of a filling depth of 7m and Landfill life of 15 years.

**Plasma Gasification over Landfills**

Gasification is superior to landfilling MSW for a number of reason. Landfill are toxic to the environment due to the production of toxic liquid leachate and methane gases. Decomposition and chemical reactions among the waste produces liquids that leach out and may contaminate ground water. Decomposition of organic matter produces methane, which is a potent greenhouse gas. Other chemicals may be produced that toxify the air around a landfill and may be harmful to neighbors. The EPA has a lengthy protocol of airborne and liquid chemicals that must to contained and monitored into eternity for every landfill.

Modern landfills must be constructed with liners and leachate drains. These facilities area becoming increasingly expensive as more environmental regulations come into existence. When landfills are closed, they must be capped and monitored indefinitely. Despite expensive management strategies, the only good solution for landfills is to avoid them. Plasma gasification is an ideal treatment strategy to divert waste from landfills and create beneficial uses for the material by maximizing recycling of valuables and cleanly use the rest for its fuel value. The carbon impact of plasma gasification is significantly lower than other waste treatment methods and is rated to have a negative carbon impact compared to allowing methane to form in landfills.

**Plasma Gasification over Incineration**

Gasification is superior to incineration, and offers dramatic improvement in both its environmental impact as well as its energy performance. Incineration has long had problems with the formation of dioxins and other critical pollutants. Incinerators are high-temperature burners that use the heat generated from the fire to run a boiler and steam turbine to produce electricity, very similar to conventional coal-fired power plants. During combustion, complex chemical reactions take place that bind oxygen to various molecules and form pollutants such a sulfur oxides, nitrogen oxides and dioxins.

These pollutants pass through the smokestack unless exhaust scrubbers are put in place to clean the gases. Gasification by contrast is a low oxygen process, and fewer oxides are formed. The scrubbers for gasification are placed in line and are critical to the formation of clean gas. Scrubbers in a gasification system are integral to the operations of the system regardless of the regulatory environment.

For combustion systems, the smokestack scrubbers offer no operational benefit and are put in place primarily to meet legal requirements. The ash from incinerators is also highly toxic and is disposed of in landfills, while the slag from plasma gasification is safe because all of the ash is melted and reforms in tightly bound molecular structure.

**Comparison of Plasma Gasification Technology with Conventional disposal Methods**

Plasma gasification technology is a method which has many purported advantages in waste management in comparison to other conventional disposal method. Plasma gasification method can be applied to almost all kind of wastes, except nuclear wastes, however, other conventional methods may not. Additionally, it require minimal presorting of solid wastes unlike other conventional methods such as incineration. Plasma gasification technology is more environmentally friendly method than the other treatment methods in terms of by-products. While syngas, which mainly comprise CO and H2, can be used for producing energy, vitrified slag can be utilized to generate rock wool floor tiles, roof tiles etc. In addition to producing environmental friendly by –by product, this technology has important advantages over conventional methods in terms incineration gas emission. While high amounts of harmful gases are sent to the atmosphere in incinerations or land filling method, much lower emission is produced in plasma gasification technique. Therefore, plasma gasification can be thought as an effective alternative method that can be used instead of land filling and incineration method due to these environment advantages .in addition to environmental advantages of plasma gasification method over conventional disposal techniques, it has economic advantages too. Plasma gasification technique has more revenue sources than the other techniques and these revenue sources can be generally stated as production of electricity, tipping fees, sales of slag and recyclables. Among these revenue sources, generation of electricity can be very important factor. For example, while 816 kWh electricity can be generated from same amount of MSW by mass burn technology. Therefore, this difference affects revenue amount significantly.

Plasma gasification technology especially has many advantages in comparison with incineration method one common conventional techniques for municipal waste disposal. Incineration and plasma gasification method is compared with each other based on selected seven criteria.

**Table No. 6 Comparison of incineration and plasma gasification method**

| Criteria | Incineration | Plasma Gasification |
|---|---|---|
| Emission of pollutant | High | Very Low |
| Material recovery | Lower | Higher |
| Energy recovery | Lower | Higher |
| Formation of ash | Exist | No exist |
| Disposal cost for by-products | Exist | No exist |
| Moisture of waste | Important | Not Important |
| Sorting of waste before feeding | Important | Not Important |

**Environmental Sustainability of Plasma Gasification**

Plasma gasification represent a clean and efficient option to convert various feed stocks Into energy in an environmentally responsible manner (Nedcorp Group, 2009, Anyaebunam 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, liquid fuels or other sustainable source of energy.

The Georgia Tech PARF lab conducted serval 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 result are as follows;

1. The percentage weight loss of the MW 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, detectable levels (BDL) in both experiments and also far below the permissible standards established by US EPZ.

4. Output gas composition: Table shows the output syngas composition for experiment without soil and with soil respectively in part per million:

**Table No. 7 Output Gas Composition**

| Output Gas | Ex-situ Experiment Without soil (PPM) | In – Situ Experiment With soil (PPM) |
|---|---|---|
| Hydrogen ($H_2$) | >20,000 | >20,000 |
| Carbon Monoxide (CO) | 100,000 | >100,00 |
| Carbon Dioxide ($CO_2$) | 100,000 | 90,000 |
| Nitrogen Oxides ($NO_x$) | <50 | 100 |
| Hydrogen Sulfide ($H_2S$) | 100 | 80 |
| Hydrogen Chloride (HCL) | <20 | 225 |
| Hydrocarbons | >5,000 | <4,500 |

PPM = Parts per million

**Low emissions**

Less than 0.01 NG/NM3 of Dioxins/Furnace emission result in PG. The pollutants (Nox, Sox and particulate matter are significantly low in PG Process. sulfur reports as Hydrogen Sulfide ($H_2S$). Easier to clean than Sox. Tars are cracked prior to leaving Plasma Gasifier

The rate of Carbon dioxide emission (Circeo L.J, 2012) per MWH of electricity produced shows (EPA Documents: www.epa.gov/ceanenergy/ emissions.htm) that while incineration of MSW emits 2,988 pounds of $CO_2$ 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 emission of NOx, SOx, dioxins and furans. In summary, when compared to conventional incineration or traditional gasification technologies, the Plasma Gasification technology and its plasma torch system offer the following benefits listed in table.

**Table No. 8 Plasma Gasification Compared to Incineration and other Gasification Process**

| 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 | Operations 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 down stream process equipment by selection of oxidant and torch power consumption |
| Multi 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 available of the gasification system |

**CONCLUSION**

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. 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 verified 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 system 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 emission 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 resource 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 or carbon dioxide .hence there will be reduction of over 2300 MT/day of land filled greenhouse gas emission 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 area-specific 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.