Annexure A

Description of Thermal Processing Technologies – Incineration, Pyrolysis, Gasification and Plasma Arc Gasification

THERMAL PROCESSING TECHNOLOGIES

THERMAL PROCESSING TECHNOLOGY

Combustion is a chemical reaction in which carbon, hydrogen, and other elements in the waste combine with oxygen in the combustion air, which generates heat. Usually, excess air is supplied to the incinerator in order to ensure complete mixing and combustion. The combustion principle gas products include carbon dioxide, carbon monoxide, water, oxygen, and oxides of nitrogen. Excess air is also added to the incinerator to regulate operating temperature and control emissions. Excess air requirements will differ with waste moisture contents, heating values, and the type of combustion technology employed.

Thermal treatment systems are designed to maximize waste burn out and heat output while minimizing emissions by balancing the three "T"s: — time, temperature, and turbulence— plus oxygen (air). The heterogeneous nature of municipal solid waste requires that waste-to-energy systems be carefully designed to operate efficiently over a wide range of waste input conditions. The low caloric waste streams, common in Indian cities, are outside the design parameters of most commercially available packaged MSW combustion technologies, which mean that the waste stream will probably have to be "upgraded" by removing inert fractions, non-combustibles, and water vapor before it can be burnt.

A subset of municipal waste combustion plants is a facility that is designed to produce energy from the combustion of the MSW [Waste-to-Energy (WTE)]. Depending upon the pretreatment methodology, there are mainly two types of MSW combustion technologies available.

- Unprocessed solid waste combustion technology (also known as Mass Burning)
- Thermal Treatment in the absence or minimum of oxygen (also known as Pyrolysis and Gassification)
- Processed solid waste combustion technology (also known as RDF burning)

"Mass burning" is being considered as moving bed combustion, which is the dominant WTE technology in the U.S., Japan and in other countries.

Mass Burn Incineration

Mass-burn facilities are generally the simplest in design of the WTE facilities, with a single combustion chamber that is generally used to raise steam to drive electrical generators and/or provide industrial process heat. Trucks carrying MSW are unloaded in a large enclosed bunker.

An overhead "claw" crane scoops materials and deposits them at the feed end of a moving metal grate, which are a set of slowly rotating cylinders. This favors the "mass burning" process because it does not require pre-processing of the feed and is easy to control. However, because of the large size of the items moving through the combustion chamber, the rates of heat, mass transfer and combustion are relatively slow. Therefore, a very large grate and combustion chamber is required and the rate of heat generation per unit volume is correspondingly low. The temperatures generated in the mass-burn combustion chamber are in the order of 950 C.

Mass burning of waste can be achieved by the use of a rotary kiln. Rotary kilns use a turning cylinder, either refractor or waterwall design, to tumble the waste through the system. The kiln is declined, with waste entering at the high elevation end and ash and non-combustibles leaving at the lower end. Rotary combustors may be followed by a traveling or reciprocating grate to further complete combustion.

A typical facility consists of two or more combustors that are sized to properly fire or burn the area's municipal solid waste during its peak generation period. Typically, at least two combustor units are included to provide a level of redundancy and to allow waste processing at a reduced rate during periods of scheduled and unscheduled maintenance. Mass-burn facilities today generate a higher quality steam, (i.e., pressure and temperature) compared to modular systems. This steam is then passed through a once-through turbine generator to produce electricity or through an extraction turbine to generate electricity and provide process steam for heating or other purposes. Higher steam quality allows the use of more efficient electrical generating equipment, which, in turn, can result in a greater revenue stream per ton of waste. **Figure 1** shows a cross-section of a modern mass-burn facility.

Source: Cardiff University, Waste Research Station

Figure 1: Cross Section of a Mass Burn Incineration Plant

1. Waste holding area/pit
2. Grab
3. Feed hoppers
4. Moving grate
5. Hydraulic arm to push the waste
6. Air holding chamber
7. Ash quenching
8. Boiler
9. Flue gas cleaning system
10. Flue gas cleaning system
11. Stack

The system of a typical mass burn plant for municipal solid waste with energy recovery can be described as follows:

- Waste is received into a pit where an overhead crane removes oversized items and mixes the waste to evenly distribute materials and moisture
- The crane feeds the waste into a charging hopper from which it is fed on to the grate, usually by means of a hydraulic ram
- The grate agitates and transports the waste across the combustion chamber, promoting combustion efficiency
- Air for combustion is introduced from under the grate (underfire air) and from nozzles located in the furnace above the grate (overfire air). Underfire air initiates combustion and cools the grate. Overfire air helps to mix the combustion gases, ensures more complete combustion and reduces oxides of nitrogen (NOx)
- Non-combustible (inert) material and ash are discharged from the end of the grate into a water quench tank, from where they are removed for further treatment, and, ultimately, either recovered for use in construction or other applications, or disposed of to landfill
- Energy is transferred from the hot flue gases to water in the tubes of a waterwall boiler, generating hot water and steam. The steam is either used to turn a turbine to generate electricity or for local heating and/or power combinations
- The cooled flue gases pass through pollution control equipment including scrubbers (for acid gas removal), electrostatic precipitators (for dust removal) and/or fabric filters (for fine particulate removal) and sometimes activated carbon (for additional mercury and dioxin control) before exhaustion to the atmosphere via a stack

The major advantage of a mass-burn facility over a landfill with landfill gas energy recovery is the amount of energy that it produces. However, it does have the disadvantage of producing significant amounts of air pollution, including heavy metals released during the combustion process. The ash that results from the combustion still has to be disposed of, but the volume is only about 10% of that of the original MSW.

In considering the MSW incineration option, decision makers must weigh the benefits of incineration against the significant capital and operating costs, potential environmental impacts, and technical difficulties of operating an incinerator.

Advantages:

1. Substantial reduction of the weight (up to 75%) and volume (up to 90%) of solid waste
2. Cost-effective in regions where land suitable for landfilling is scarce due to geographical constraints, Jurisdictional and political boundaries.
3. Generation of revenues from energy production

Disadvantages:

1. The technology is expensive both in terms of capital and operational costs
2. Implementation of this technology will be violation of the International norms (Kyoto Protocol and Dhaka Declaration 2004) to which India is a signatory
3. Difficult to incinerate wastes of Mumbai due to high moisture and low energy content.
4. The process generates fly ash and fuel gas residues (dependent of the technology), which has to be deposited of in a controlled landfill. In addition, Nox and other gasses as well as particles and dioxins are released from the process, therefore is needed an extensive and expensive flue gas treatment system

5. Monitoring equipment is costly and requires aggressive maintenance and servicing by trained technicians
6. Requires highly trained personnel, constant availability of technologically advanced testing and repair facilities, and a well functioning system for ensuring the quick availability of spare parts.

Incineration with or without energy recovery does not appear to be a sound option for most situations encountered in developing countries. It is not surprising, therefore, that there are few examples of successful MSW incineration in such countries and several examples of premature attempts to adopt this technology. For example, Buenos Aires, Mexico City, New Delhi, and Sao Paulo, among other cities, have had to shut down incinerators due to high costs or environmental considerations. It is important to recognize, however, that some developing countries do have considerable technical expertise and the capital necessary to install and operate incinerators.

PYROLYSIS

Pyrolysis is a thermal processes that use high temperatures to break down any waste containing carbon. Pyrolysis has a long history of industrial use. Pyrolysis systems utilize a wide range of designs, temperatures, and pressures to initiate Pyrolysis reactions. Typically, Pyrolysis systems use a drum, kiln-shaped structure, or Pyrolysis tube, which is externally heated using either recycled syngas or another fuel or heat source, to heat the Pyrolysis tube/chamber.

Basically, the organic materials are "cooked" in an oven with no air or oxygen present. No burning takes place. Most organic compounds are thermally unstable. At high temperatures, the organic compounds volatilize and bonds thermally crack, breaking larger molecules into gases and liquids composed of smaller molecules, including hydrocarbon gases and hydrogen gas. The temperature, pressure, reaction rates, and internal heat transfer rates are used to control specific pyrolytic reactions in order to produce specific products. At lower temperatures, liquid pyrolysis oils dominate. At higher temperatures, gaseous byproducts dominate.

Figure 2 presents a basic process description for a Pyrolysis system.

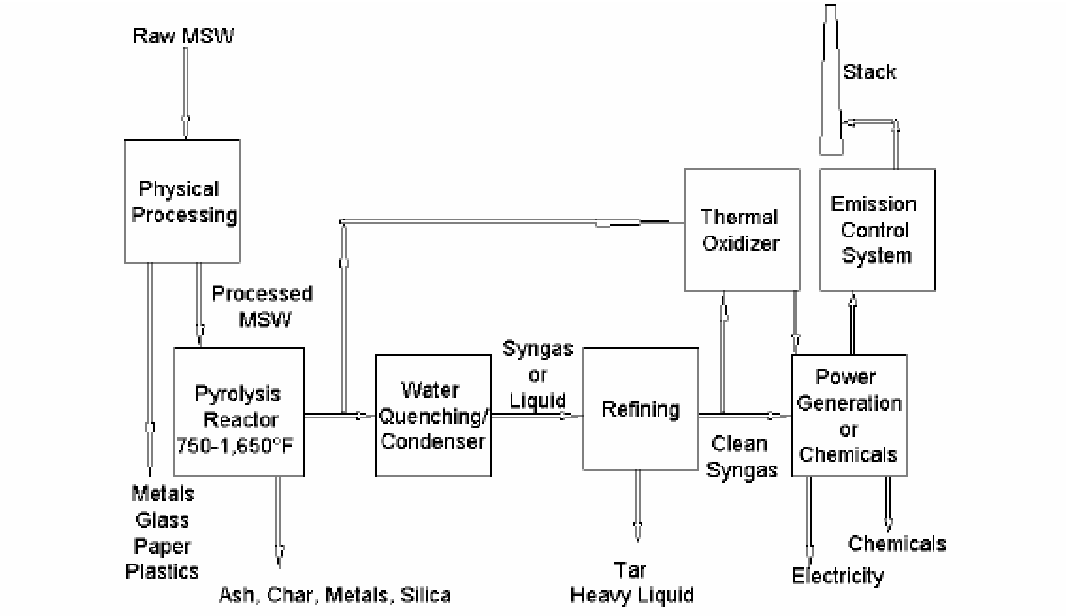

Figure 2: Typical Pyrolysis for Power Generation or Chemicals

Pyrolysis reactions are endothermic, meaning they require externally supplied heat to occur.Natural gas, propane, or syngas produced by pyrolysis can be used as a source of external heat. If the feedstock has a large higher heating value (HHV) measured, the pyrolytic process becomes more self-sufficient, and once the process starts, it uses an extremely small amount of fossil fuel.

Pyrolysis produces gases and liquids, as well as residual solids, including ash and carbon char. Some common commercial products made through pyrolysis are charcoal (for barbecuing) and activated carbon (for adsorption of liquid and gaseous emissions), depending on the nature of the feedstock.

Since inorganic materials do not enter the thermal conversion reactions, energy, which could be used to produce Pyrolysis reactions, is expended in heating up the inorganic materials to the Pyrolysis reactor temperature. The inorganic materials are cooled in cleanup processes, and heat is lost. Pre-processing is therefore required to remove inorganic materials such as grit, glass, and metal, and to enhance the homogeneity of the feedstock.

Since Pyrolysis occurs in the absence of oxygen, the feed system and Pyrolysis chamber are sealed and isolated from outside air during the processing. This is accomplished through the use of inlet and outlet knife-gates, with ram feeders to feed individual "plugs" of feedstock into the reactor as the next plug is being fed into the sealed environment.

Following the Pyrolysis reactor, the syngas may be:

- Burned directly in a thermal oxidizer or boiler, and its heat recovered for making steam for power generation. The exhaust gases then pass through emission control systems that may include fabric filters, wet and dry scrubbers, electrostatic precipitators, and/or activated carbon beds.
- Quench cooled, cleaned in emission control systems, and then burned in a boiler, reciprocating engine, or gas turbine for power generation.
- Quench cooled, cleaned in emission control systems, and then utilized for producing organic chemicals.

Char can be used to make commercial products, such as charcoal or coke, manufactured into graphite rods for carbon arc steel making, or further processed in gasification reactions

Inorganic materials in the feedstock are removed as bottom ash. They are usually combined with char, and can be separated out for disposal (if char is to be utilized as noted above) or used in making block materials.

Pyrolysis systems can process a wide range of carbon-based materials. Any organic or thermally degradable material can be processed by Pyrolysis. Historically, Pyrolysis was used to make charcoal from wood. Pyrolysis also is used to process used tires and produce carbon black, steel, and fuel to generate power. Currently, some manufacturers are using Pyrolysis to make activated carbon using coconut shells or wood as feedstock. If a homogeneous feedstock is processed by Pyrolysis, a high quality byproduct is produced.

MSW is not a homogenous waste stream. In order to make the Pyrolysis process more efficient, pre-processing of MSW is required. The pre-processing includes the separation of thermally non-degradable material such as metal, glass, and concrete debris. Also, for some Pyrolytic processes, size reduction and/or densification of the feedstock may be required. If MSW has a high moisture content, a dryer may be added to the pre-processing stage to lower the moisture content of the MSW to 25% or lower, because lower moisture content of the feedstock increases its heating value and the system becomes more efficient. The waste heat or fuel produced by the system can be used to dry the MSW. However, this may have a significant impact on economic viability and of the process.

The optimal calorific value of waste should be approximately 2000 kcal/kg for proper Pyrolysis. Since Mumbai waste is of low calorific value (~900 kcal/kg) this technology therefore is not viable option for processing with MSW as the only input. Another constraint is of air pollution. It is necessary to install and operate a battery of air pollution control equipments to reduce the emissions.

GASSIFICATION

Gasification process involves the partial oxidation of carbon-based feedstock to generate a syngas, which can be used as a fuel or for the production of chemicals. It starts with Pyrolysis and goes several more steps to further gasify the pyrolysis liquids and tars, as well as the carbon char left over from Pyrolysis. Similar to Pyrolysis, Gasification also typically rely on carbon-based waste such as paper, petroleum-based wastes like plastics, and organic materials such as food scraps.

Gasification involves using a small amount of oxygen whereas Pyrolysis uses none. Besides syngas, other by-products include liquids (mainly water used for washing the gas clean) and solid residues – ash, or char.

Figure 3 presents a basic process description for a Gasification system.

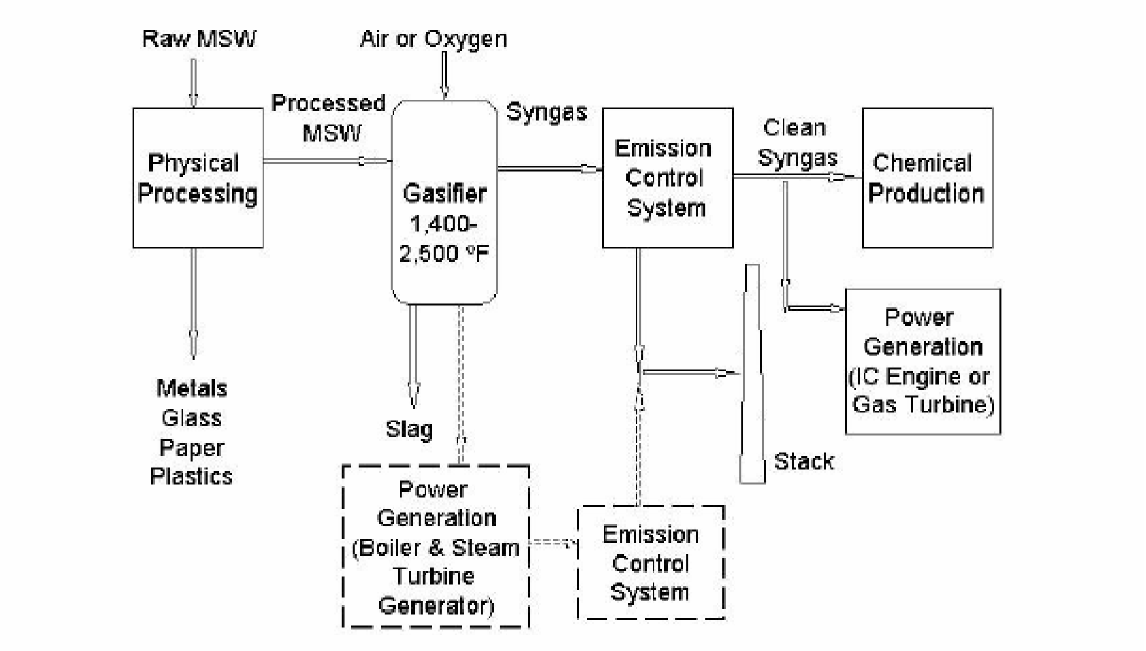

Figure 3: Typical Gasification System for Power Generation or Chemicals

Gasification, an alternative to traditional combustion, is a thermal decomposition of organic material at elevated temperatures in an oxygen-restricted environment that converts it into a low or medium BTU gas. It is claimed that this technology has several advantages over traditional combustion of MSW. The formation of dioxins and large quantities of SOx and NOx seems limited since the degradation takes place in a low oxygen environment. Instead, the nitrogen or sulfur in the waste stream end up as H_2S, N_2 or ammonia rather than SOx and NOx.

Furthermore, it requires just a fraction of the stoichiometric amount of oxygen necessary for combustion. As a result, the volume of process gas is low, requiring smaller and less expensive gas cleaning equipment. Finally, gasification generates a fuel gas that can be integrated with combined cycle turbines, reciprocating engines and, potentially, with fuel cells that convert fuel energy to electricity more than twice as efficiently as conventional steam boilers.

In gasification, two processes must take place in order to produce a useable fuel gas. In the first stage, Pyrolysis releases the volatile components of the fuel at temperatures below 600°C. The by-product of

Pyrolysis that is not vaporized is called char and consists mainly of fixed carbon and ash. In the second gasification stage, the carbon remaining after Pyrolysis is either reacted with steam and/or combusted with air or pure oxygen. Gasification with steam is more commonly called "reforming" and results in a hydrogen and carbon dioxide rich "synthetic" gas (syngas). Typically, the exothermic reaction between carbon and oxygen provides the heat energy required to drive the Pyrolysis and char gasification reactions.

Similar to Pyrolysis, gasification processes also have four stages:

- Pre-treating the waste, which usually involves sterilizing it and separating out some of the recyclables, especially glass, grit and metal (which have no calorific value);
- Heating the remaining waste, mainly organic pulp, to produce gas, oils and char (ash);
- 'Scrubbing' (cleaning) the gas to remove some of the particulates, hydrocarbons and soluble matter; and
- Using the scrubbed gas to generate electricity and, in some cases, heat (through combined heat and power).

Gasifiers are typically characterized as being horizontal or vertical, and utilize one of three specific reactor designs: 1) fixed-bed, 2) fluid bed, or 3) entrained flow. In fixed-bed gasifiers, the feedstock is usually fed through the system on a stationary or moving grate. The air or oxygen is injected either up, down, or in a cross flow. In an updraft Gasifier, the air or oxygen is injected from the bottom and the syngas exits at the top. In a downdraft design, the air enters at or near the top of the Gasifier, and the syngas exits the side or bottom.

In a fluid bed design, the Gasifier is filled with inert particles (usually sand or alumina). The feedstock is fed either directly into or above the bed. A high velocity gas, usually oxygen or air, is injected below the bed, causing the feedstock and inert particles to be suspended in the bed. The feedstock and bed materials are continuously stirred, resulting in uniform temperatures and reactions, and improved heat transfer. Bubbling bed and circulating fluid bed designs are commonly used to enhance fluidization and turbulence.

Entrained flow Gasifiers use large quantities of oxygen injected from the top or side of the reaction chamber to create higher operating temperatures. This process is capable of producing a cleaner, tar-free syngas while keeping the gasified byproducts in a molten state, allowing for easier disposal. This slag is both inert and virtually carbon free.

Following the Gasifier, the syngas may be:

- Burned directly in a thermal oxidizer or boiler, and its heat recovered for making steam for power generation. The exhaust gases then pass through emission control systems that may include fabric filters, wet and dry scrubbers, electrostatic precipitators, and/or activated carbon beds.
- Quench cooled, cleaned in emission control systems, and then burned in a boiler reciprocating engine or gas turbine for power generation.
- Quench cooled, cleaned in emission control systems, and then utilized for producing organic chemicals.

If low temperature Gasification is used, the inorganic materials in the feedstock will be recovered as a powdery to clinker-like bottom ash. This can be disposed of or used for the manufacture of block materials. If high-temperature gasification is used (typically above about 1,100°C), the inorganic materials will be subjected to temperatures above their melting points, forming a molten slag. The slag flows out a tap hole in the bottom of the gasifier, into a water bath. There, the slag is quench cooled, forming a glassy, non-hazardous slag material. This can be disposed of safely or used for the production of roofing tiles, sandblasting grit, or asphalt filler.

The optimal calorific value of waste should be approximately 2000 kcal/kg for proper Gasification. Since Mumbai waste is of low calorific value (~900 kcal/kg) this technology therefore is not viable option for processing with MSW as the only input. Another constraint is of air pollution. It is necessary to install and operate a battery of air pollution control equipments to reduce the emissions.

Plasma Arc Gasification

Plasma is a hot ionized gas resulting from an electrical discharge. Plasma technology uses an electrical discharge (some use AC, some DC, and some a combination) to heat gas, typically air, oxygen, nitrogen, hydrogen, or argon, or combinations of these gases, to temperatures above 7,000°F. The heated gas, or plasma, can then be used for welding, cutting, melting, or treating waste materials.

Figure 4 presents a basic process description for a Plasma Arc Gasification system.

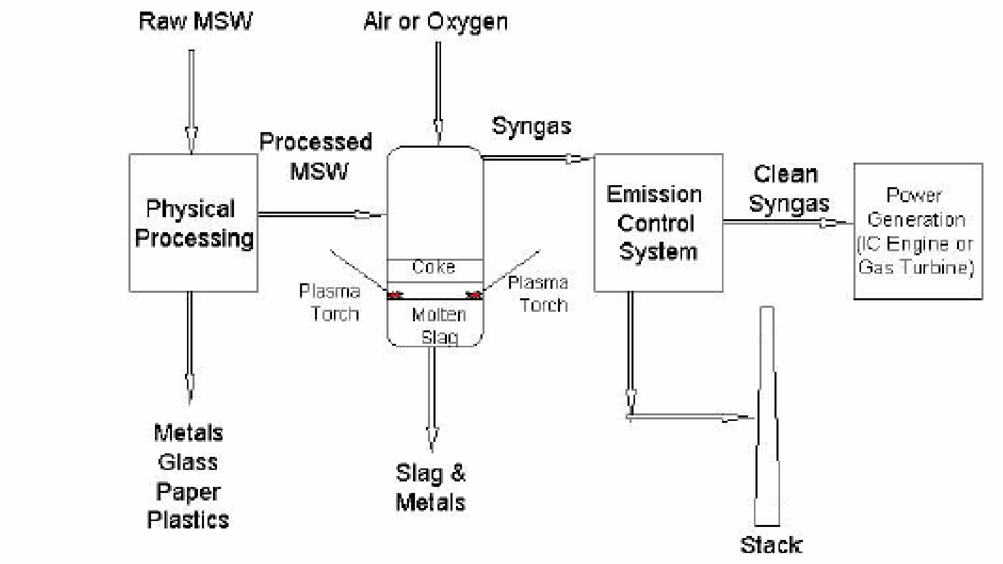

Figure 4: Typical Plasma Gasification System for Power Generation

Most of the use of plasma arc technology has been for melting incinerator ash or for thermally decomposing hazardous or medical wastes. Only very recently has development occurred for using plasma technology integrated with gasification technologies to process MSW. This has great potential to convert MSW to electricity more efficiently than conventional pyrolysis and gasification systems, due to its high heat flux, high temperature, almost complete conversion of carbon-based materials to syngas, and conversion of inorganic materials to a glassy, non-hazardous slag.

There are two types of plasma torches, the transferred torch and the non-transferred torch. The transferred torch creates an electric arc between the tip of the torch and either a metal bath or the conductive lining of the reactor vessel wall. In a non-transferred torch, the arc is produced within the torch itself. Plasma gas is fed into the torch, heated, and then exits through the tip of the torch.

There are several approaches to the design of plasma gasification reactors. In one approach, developed by Westinghouse Plasma Corporation (plasma torch manufacturer) and Hitachi Metals (plasma gasification system developer and user), a medium pressure gas (usually air or oxygen) flows through a water-cooled, non-transferred torch, outside of the reactor. The hot plasma gas then flows into the reactor to gasify the MSW and melt the inorganic materials.

Another design is an in-situ torch, where the plasma torch is placed inside the reactor. This torch can either be a transferred or non-transferred torch. When using a transferred torch, the electrode extends into the gasification reactor and the arc is generated between the tip of the torch and the molten metal and slag in the reactor bottom or a conducting wall. The low-pressure gas is heated in the external arc.

Alternatively, a non-transferred torch can be used for creating plasma gas within the torch, which is injected into the reactor.

Several suppliers utilize a completely different approach. In these designs, the reactor is heated by electric induction coils or an electric arc produced by graphite rods, forming a molten metal and slag bath. The MSW enters the reactor, where it is subjected to high temperatures, resulting in partial gasification of the feedstock. From there, the syngas exits the reactor. The plasma torch is situated either in a secondary reactor or in a recycle line, which goes back to the first reactor, assuring complete gasification of the feedstock.

Proponents of the in-situ torch claim its advantages include better heat transfer to MSW and a hotter reactor temperature, resulting in more complete conversion to syngas. The main disadvantage is the potential corrosion of the torch from hot MSW and gases. An external torch is more protected from the corrosive effects, which can prolong the mechanical integrity. A disadvantage of an external torch is the possibility of a somewhat lower reactor temperature, resulting in lower conversion of the MSW. Electrodes in all designs experience some corrosion and must be replaced.

The first two approaches have been applied to small-scale commercial waste and medical waste processing units. The throughput of the largest external system is approximately four tons/hour and the throughput of the largest internal system is approximately 10 TPD. The Westinghouse/Hitachi design has been scaled up to 83 tpd per reactor at Utashinai, Japan, which treats a combination of MSW and auto shredder residue.

Plasma arc gasification typically occurs in a closed, pressurized reactor. The feedstock enters the reactor, where it comes into contact with the hot plasma gas. In some designs, several torches arranged circumferentially in the lower portion of the reactor help to provide a more homogeneous heat flux. When used for gasification, the amount of air or oxygen used in the torch is controlled to promote gasification reactions.

Syngas can either be burned immediately in a close-coupled combustion chamber or boiler, or cleaned of contaminants and used in a reciprocating engine or gas turbine. In the first approach, the exhaust gases are cleaned after combustion, in an emission control system. Hot gases flow through the boiler, creating steam used for power generation in a conventional steam turbine. In the second approach, the syngas is cleaned before it enters the engine or gas turbine.

As noted above, the primary solid output from plasma facilities is a glassy slag, the result of melting the inorganic fraction of the waste. Any waste processing facility generating an ash or slag is required by the United States Environmental Protection Agency (USEPA) to subject it to a Toxicity Characteristic Leaching Procedure (TCLP) test. The TCLP test is designed to measure the amount of eight elements that leach from the material being tested. Data from existing facilities, even those processing highly hazardous materials or medical waste, show results that are well below regulatory limits.

While there are only a few plasma torch manufacturers, there are over a dozen companies that have taken the plasma technology and are developing it for use in MSW gasification. This has led to several suppliers claiming the same operational experience; i.e., several suppliers that incorporate Westinghouse plasma torches claim the experience in the Hitachi Metals plants as being their own or representative of how their system would perform.

Byproducts of Plasma Arc Gasification are similar to those produced in high-temperature Gasification. Due to the very high temperatures produced in Plasma Arc Gasification, carbon conversion nears 100%.

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ANNEXURE B

Description of Biological Processing Technologies-Composting, Anaerobic Digestion (BioMethanation) and Bioreactor Landfill.

AEROBIC COMPOSTING

Composting is a natural microbiological process where bacteria break down the organic fractions of the municipal-solid-waste stream under controlled conditions to produce a pathogen-free material called Compost that can be used for potting soil, soil amendments (for example, to lighten and improve the soil structure of clay soils), and mulch. The microbes, fungi, and macro-organisms that contribute to this biological decomposition are generally aerobic. Systematic turning of the material, which mixes the different components and aerates the mixture, generally accelerates the process of breaking down the organic fraction. The composting process takes from 14 to 180 days.

The high organic content in the municipal waste stream of developing countries is ideal for composting. It is a simple low cost technology, although processing methods can be deployed to encourage the composting process. As a familiar process, it is unlikely to meet significant public opposition during the planning process. Almost 1/3 of the waste tonnage is “lost” to CO_2 and water through the composting process. The resulting compost material can be put to beneficial use on land. Composting is interesting to the municipal waste manager because:

- Putrescible (decomposable) organic waste represents the largest fraction of the solid waste
- Recovery of organic materials through separation and composting decreases the amount of waste requiring final disposal, saving landfill space and prolonging the life of existing landfills and dumps.
- Composting can accommodate and help to manage seasonal fluctuations in waste volume or composition, combining such diverse waste streams as leaves, kitchen wastes; agricultural and crop residues; food processing wastes; and sewage sludge.
- Health hazards associated with untreated disposal of putrescible wastes decrease significantly under controlled conditions of composting, where the heat of the bacterial action actually sanitise the materials; kills pathogens; and deactivates weed seeds and fungal spores.
- Compost is a source of valuable mineral and organic materials, including slow-release nitrogen
- Application of compost can improve the soil structure since compost mitigates compaction from high-use, maintaining the ability of air and water infiltration to the root zones. It can therefore be applied to sports fields; municipal parks; green areas; cemeteries; golf courses; municipal gardens and nurseries etc.
- Compost can be used to re-establish soil where it has been completely loss, like for example mines, gravel pits and the like.
- Blending of compost with agricultural chemicals can reduce the required levels of fertiliser, herbicide and fungicide.
- Compost lasts longer than other traditional fertilisers, usually 3 times longer; the nutrients are released over a period of three to ten years, depending on the local conditions and the intensity of use, becoming a kind of ‘soil bank’.
- Compost improves the water holding capacity for soil prone to drought cycles and conversely the water infiltration and drainage improvement in soils prone to rainy seasonality.

Description of Composting Technology

There are about 10 basic composting ‘technologies’, all of which are based on the biochemical activity of soil microbes and bacteria. This document is limited to the discussion of aerobic composting (**Figure 5**).

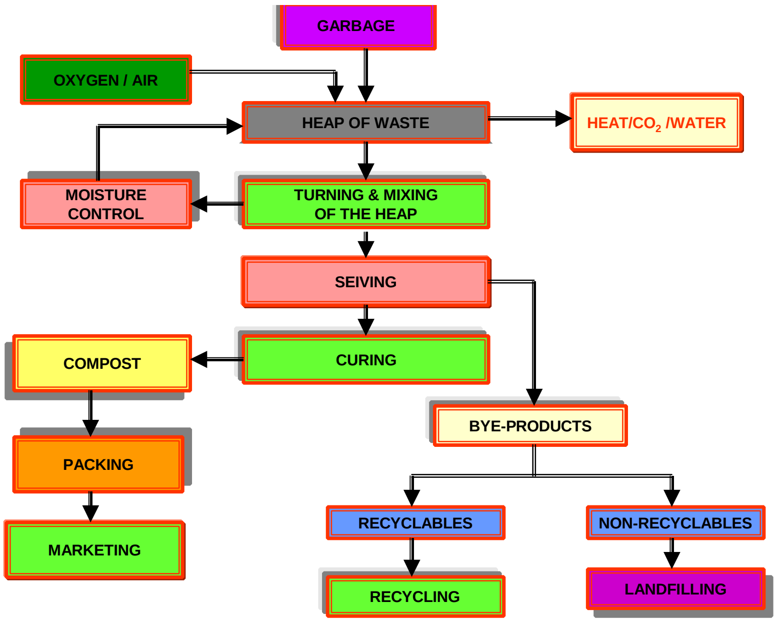


Figure 5: Process Flow Diagram of Aerobic Composting Process

There are three main stages to aerobic composting. These include:

- **Phase 1**, the mesophilic growth stage, which is characterised by bacterial growth and temperatures of between 25 and 40 °C.
- **Phase 2**, the thermophilic stage when bacteria, fungi and actinomycetes (first level consumers) present at temperatures of 50-60 °C, breakdown cellulose, lignin and other resistant materials. The upper limit of the thermophilic stage can be as high as 70 °C and it is necessary to hold the temperature at this level for a minimum of 1 day to ensure pathogens and contaminants are destroyed.
- **Phase 3** is the maturation stage, where temperatures stabilise and some fermentation occurs, converting the material to humus through nitrification reactions. Ultimately the objective is to produce a material, which is stable and this can be judged by the carbon to nitrogen (C/N) ratio; a well-composted material has a low C/N ratio. For example untreated new organic waste has a C/N of 30 whereas windrowed material is 15.

Size and configuration of the composting plant depends upon the quantity of materials to be processed and the duration of activities, including active composting, curing, and storage. Typical duration for composting is 45 to 60 days, curing or maturation requires 30 to 120 days, and storage is dependent on the amount of time until the product can be marketed or removed for use.A good site for composting is a piece of land that is nearly flat, with a good distance from ground or surface water. A 2% to 4% grade is ideal for composting:

There are two fundamental types of composting techniques: open or windrow composting, which is done out of doors with simple equipment and is a slower process, and enclosed system composting, where the composting is performed in a building, a tank, a box, a container or a vessel.

A comparison of these technologies is presented in **Table 1**.

Table 1: Comparison of Composting Technologies

Sr. No	Parameter	Windrow Composting	Closed Vessel Composting
1	Capital cost (for the same flow of Materials)	Low to medium cost of equipment & Infrastructure	Medium to high depending on what we see as an enclosure
2	Technical applicability and durability (after training)	• Multifunctional • Extensive capacity • Easy to operate • Long life time • Can accommodate many types of materials in one system	Inflexible • Simple to operate, difficult to maintain • Renew of equipment and machinery more frequently but not necessarily any less than a mobile piece of equipment used for windrows
3	Equipment, personnel, energy	Use of equipment that municipalities have access to already High labour to capital ratio means continued or increased employment	Requires significant capital purchases • High capital to labour ratio usually results in few workers • Often energy intensive
4	Design requirements	High land requirement • Accommodate flexible volumes • More selectively in sites and initial design due to possible on and off-site impacts	Low land requirement • Limited flexibility in volume • Less constraints in selecting sites due to built in controls for on and off site impacts
5	Environmental issues	• Limited control of air and water discharge • Limited control of vectors and pest attraction	Significant control of air and water discharge • Better vector attraction control
6	Source of 'technology'	Necessary equipment is present in most municipalities.	Specialised equipment most often acquired from international companies.
7	Initiative and management	Can be initiated and managed by Municipalities, individuals, farmers, NGOs, CBOs, civic organisations, MSEs or other formal or informal groups.	Level of technology and equipment usually demands the involvement of the municipality, the national government (as aid recipient or bank guarantor) and international suppliers.
8	Commonest technologies	Active windrows Aerated static piles	• Agitated bed • Hot Box • Drum composter

The turned **windrow system** is the technique most readily associated with the large-scale composting of wastes. A windrow is a pile that is generally 1.5 – 2 times as wide as it is height, with its length determined by the amount of material available. Windrows are generally placed parallel to one another, with enough room in the middle for turning and power equipment to pass through.

In-vessel systems, such as drum or agitated bed technologies, or any technical system enclosed in a building, require complex equipment. These systems are highly engineered, capital intensive and require day-to-day management due to the automated systems and the design, which has necessarily incorporated mitigation of potential worker health, environmental impact and nuisance conditions. They also use substantial amounts of energy. On going operation and maintenance is critical and less forgiving than more passive approaches and it requires access to specialised pieces of equipment that usually have to be manufactured and delivered at a high price. The equipment may have been designed for specific climatic conditions and may not be universally applicable. They allow for the use of less land and they produce compost in a shorter time than open systems.

Large-scale composting operations have three requirements: sufficient land for the placement of the windrows, some means of turning the windrows regularly to speed the decomposition process and prevent any anaerobic conditions, and a market for the compost that is produced. Its economic viability is driven primarily by the disposal costs avoided. Windrow composting processes are simpler, require less capital, and use less energy. They generally rely more on land and labour and less on machinery.

Open windrow composing processes are relatively low-technology solutions. They are most effective in situations where the proportion of organic material in the waste stream is high and markets for the product are readily available. Operational control is through selecting and preparing a suitable waste to be composted and maintaining optimal temperature, moisture and aeration conditions in the active windrows.

The input quality flexibility of open windrow composting is limited, being only able to process organic wastes. The C/N of the mixture should be in the range of 25:1 - 30:1. The initial moisture content should be between 40% and 60%. The list of materials suitable for composting is almost endless because composting is a flexible process. However, the municipal waste stream contains increasing quantities of glass, plastics, metals and hazardous materials, which make operations difficult and can contaminate the finished compost. Sand, dust and inert materials and heavy metal containing wastes are to be excluded from composting to get quality compost.

Open windrow composting has good input quantity flexibility with the capacity of any facility limited to the land area of the facility. The technology maturity of open windrow composting is good, with large-scale open windrow composting being done in India for many years. Similarly, the local availability of open windrow composting is high, with some key technologies such as windrow turning equipment imported.

The primary environmental impacts of open windrow composting facilities are from odours and leachate. Experience has shown that proper oxygen levels in the compost at all times can reduce odor emissions. This means that the compost should be turned more often in the beginning of the process in order to prevent development of anaerobic zones. Experiments with turning technology indicate that spraying water with very fine droplets into the air when turning the piles can also reduce the odor problem because the odorous molecules will dissolve into the water droplets and be carried to the ground. Surrounding the compost facility by earthen walls with trees planted on them can also reduce odor emissions. From resource conservation point of view the technology is good, with most of the organic material being recovered.

Odours can also be generated if unprocessed or processed feedstock containing putrescible materials has been stored for long period. Every attempt should be made to process the feedstock as soon as possible after it has arrived, while it is optimal condition for composting.

Leachate is a liquid released during the composting process, and practically every composting operation will generate small quantities of leachate. Leachate pools are a result of poor housekeeping and may act as a breeding place for flies, mosquitoes, and create odour problems. Improper managed, leachate can contaminate ground- and surface water with excess nitrogen and other contaminants. For these reasons, leachate must be contained and treated.

It is advisable for the composting facility design to have the area paved and equipped with drains leading to a leachate collection tank or pond. Leachate may be transported and treated at a wastewater treatment plant or mixed as a liquid source with the incoming material. Leachate may contain pathogens, and therefore must not be returned to material that has been through the pathogen destruction stage of the compo sting process.

Public perception and confidence in composting is generally positive and the product is well supported in the market.

BIOMETHANATION

Biomethanation involves controlled biological degradation of organic wastes by microbial activity in the absence of oxygen. The process involves the anaerobic (without air) decomposition of wet organic wastes to produce a methane-rich biogas fuel and a small amount of residual sludge that can be used for making compost. It takes place in digester tanks or reactors, which enable control of temperature and pH levels for optimising process control. Methane-rich gas produced is suitable as fuel for energy generation. The digestate sludge is also produced, which is suitable for enriching compost materials. Input preparation or source separation is required to ensure that waste is free of non organic contamination.

Advantages of Biomethanation are:

- Generation of gaseous fuel;
- Feasibility even on a small-scale;
- Avoidance of Green house gases emission to the atmosphere
- Freedom from bad odor, rodent and fly menace, visible pollution and social resistance;
- Modular construction of plant and closed treatment needs less land area; and
- Production of high-grade soil conditioner

As shown on **Figure 6 and Figure 7,** the overall process requires three to four stages involving mechanical processing, one or two distinct anaerobic decomposition phases, and an aerobic or other stabilizing process. During digestion, the two different processes of acidification and methanogenesis require different temperatures and pH levels for optimal process control.

Pre-treatment of waste is required for preparation of organics and separation of dry recyclables. Following digestion, a composting stage is usually required for curing, as the anaerobic process does not necessarily destroy all pathogens.

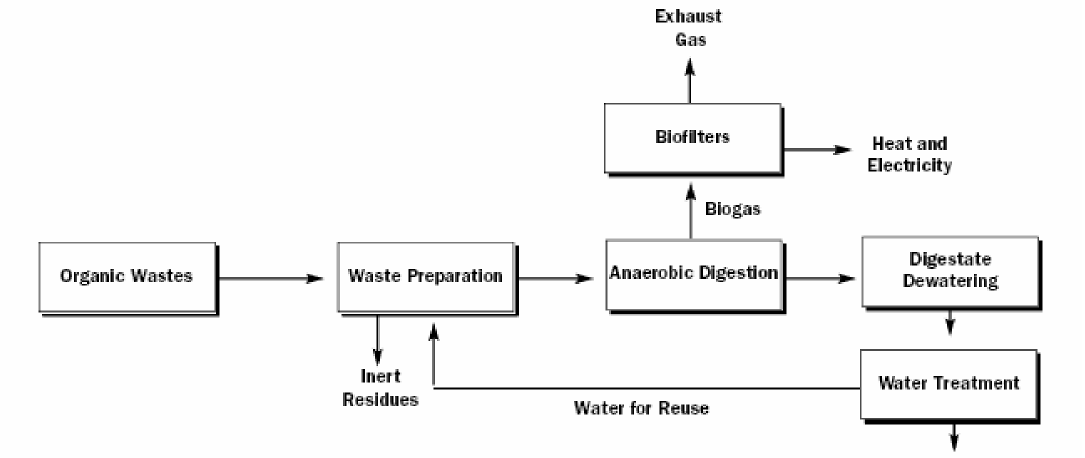


Figure 5: Anaerobic Digestion Flow Chart

Biomethanation systems use closed reactors to control the anaerobic process and to collect all of the biogas fuel produced. The yield of biogas depends on the composition of the waste feedstock and the conditions within the reactor. The rate of anaerobic digestion can be increased by operating in certain temperature ranges.

The modern anaerobic digestion treatment processes are engineered to control the reaction conditions to optimize digestion rate and fuel production. Wastes remain in a digester that is operating in the mesophilic (30 – 35 C) range for a varying period of 10 – 40 days, the duration being dictated by differing technologies, temperature fluctuations and waste composition.

The gas produced contains methane (55-70% by volume), carbon dioxide (30-45% by volume), some inert gases and sulphur compounds such as hydrogen sulphide (200 –4000 ppm by volume). Typically 100-200 m^3 of gas is produced per ton of organic MSW that is digested.

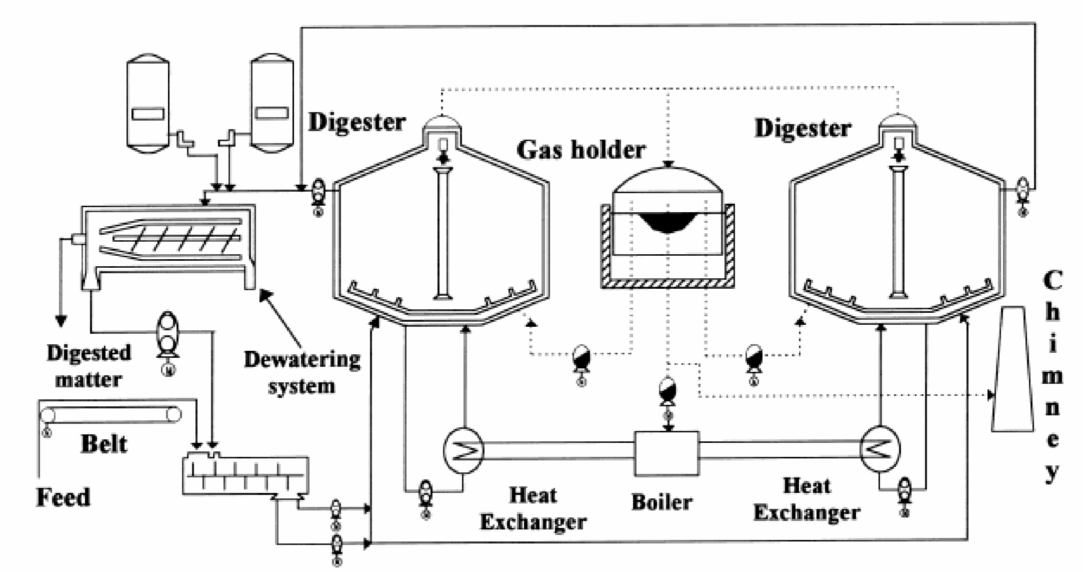


Figure 6: Elements of a typical Semi-dry anaerobic digestion process of organic solid waste

Biogas is generated from the organic fraction of MSW at a typical yield of 0.4 m^3 per kg Volatile Solids (ash-free dry wt.) added. The composition is typically 55% methane, 45% carbon dioxide, with traces of hydrogen, hydrogen sulfide, and water vapor. This gas is combustible without purification and can be used directly for heating, cooking, and running generators and internal combustion engines. These uses often require some passage through a condensation trap to reduce the water content. Biogas can also be upgraded (by removal of carbon dioxide and hydrogen sulfide) and compressed for use in motor vehicles or distribution into the gas pipeline.

A wide variety of systems have been developed to anaerobically treat MSW. They can be split into a variety of categories as described below.

1) Wet or Dry Process:

In the Wet process the MSW feedstock is slurried with a large amount of water to provide a dilute feedstock of 10-15% dry solids.

In the Dry process the feedstock used has a dry solids content of 20 – 40%.

2) Batch or Continuous:

In a Batch process the reactor vessel is loaded with raw feedstock and inoculated with digestate from another reactor. It is then sealed and left until thorough degradation has occurred. The digester is then emptied and a new batch of organic mixture is added.

In a Continuous process the reactor vessel is fed continuously with digestate material, fully degraded material is continuously removed from the bottom of the reactor.

3) Single Step/Multi-Step:

In a Single Step process all digestion occurs in one reactor vessel.

The Multi-Step process consists of several reactors; often the organic acid forming stage of the anaerobic digestion process (acetogenesis) is separated from the methane forming stage (methanogenesis). This results in increased efficiency, as the two microorganisms are separate in terms of nutrient needs, growth capacity and ability to cope with environmental stress. Some multistage systems also use a preliminary aerobic stage to raise the temperature and increase the degradation of the organic material. In other systems the reactors are separated into a mesophilic stage and a thermophilic stage.

4) Co-digestion with Animal Manure / Digestion of MSW alone

Co-digestion with Animal Manure – The organic fraction of the MSW is mixed with animal manure and the two fractions are co-digested. This improves the carbon/nitrogen ratio and improves gas production.

Digestion of MSW Alone – The feedstock contains the organic fraction of MSW alone, slurried with liquid, no other materials are added. The current leading industrial concepts are:-

Dry Continuous Digestion - Continuously fed vessel with dry digestate matter content of 20-40%. Minimal water addition makes the overall heat balance very favorable for operation at thermophilic temperatures.

Dry Batch Digestion - Batch system fed with dry digestate matter content 20- 40%. During digestion, when the reactor is sealed, leachate collected from the base of the reactor is recirculated to maintain a uniform moisture content and to redistribute soluble substrates and bacteria. A disadvantage of this system is that increased pretreatment is required to provide a suitable refined digestate material.

Leach-Bed Process - Similar to dry Batch digestion, however, leachate from the base of the reactor is exchanged between established and new batches to improve startup , inoculation and removal of volatile acids in the reactor. This is also called Sequential Batch Anaerobic Composting (SEBAC). After a while, when methanogenesis is established, the leachate flow is uncoupled and connected to a new batch.

Wet Continuous Single-Step Digestion - MSW feedstock is slurried with a large amount of water (10% solids). The system leads itself to co-digestion of MSW with more dilute feedstocks such as sewage sludge or animal manure. Effective removal of glass and stones is required to prevent rapid accumulation of these in the bottom of the reactor. The digestate requires pressing to recover liquid, (which can be recycled to mix with incoming waste), to produce a solid digestate for disposal.

Wet Continuous Multi-Step Digestion - MSW feedstock is slurried with water or recycled liquid (10% solids content) and fed to a series of reactors where acetogenesis occurs in a separate reactor to methanogenesis.

Biomethanation systems for digesting MSW are now widely used throughout the world. Anaerobic digestion of biowaste or the mechanically separated organic fraction of residual municipal waste is well established in central Europe, with a number of technology suppliers in that region dominating the market. The majority of plants are large scale, processing over 2,500 Tons of waste per day and involve complex plant design. Much of the technology is based in Europe, with Germany and Denmark leading the field in technology and in the number of successful plants in operation. To increase the rate of digestion and biogas production multi-stage processes are often used.

The major organic constituents of MSW are cellulose, hemicellulose, and lignin. These substrates are bound in particles and their solubilization and depolymerization is the rate-limiting step of decomposition of this feedstock. The input quality flexibility is low being able to only process organic waste. Only waste of organic origin can be processed in an anaerobic digester. As this makes up 30-60% of household waste there is a considerable benefit in diverting this waste from landfill. The waste must be sorted so that all inorganic products are removed from the refuse prior to entry into the digester. Ideally the refuse should be sorted at source, if not, it could be sorted by hand/mechanical means on delivery to the site. Joint treatment of municipal solid waste with animal manure/sewage slurry is a popular method. The input quantity flexibility is moderate as the facility is sized and amortised for a certain capacity. The technical maturity of these processes is high with many facilities operating overseas.

Being an enclosed technology with collection and treatment of all air and water emissions the environmental impacts of this technology is low. The recovered biogas can be used to generate green power, and the residual sludge can be land applied, composted, or converted into fertilizer pellets. The risk of air emissions and risk of water emissions are moderate with all emissions being collected and treated before discharge. The greenhouse gas emissions are taken to be moderate and solid residues are dependent on inert contamination in the incoming waste stream. The resource conservation is good with energy and organic nutrients being recovered.

Public perception and confidence in anaerobic digestion is unclear due to the minimal number of facilities operating in the country, but is expected to be fair. Amenity impacts are low due to the process being enclosed. Employment impacts are moderate in process operations due to the capital intensity of the operations, but moderate in process control and asset management.

It is difficult to discuss in detail the economics of implementing an Anaerobic Digestion Plant for MSW, because of the many factors that affect the costs and the variation in circumstances and costs between different countries. For example the following factors will have an influence on the overall treatment costs:-

- Energy Prices
- Energy Taxes & Renewable Energy Policy
- Land Prices
- Labour Costs
- Construction and material costs
- Markets for the compost/soil conditioning product and prices
- Quality of the compost produced

The homogeneity of the feed material is an important parameter from the efficiency point of view. However, heterogeneous nature of MSW necessitates incorporation of pretreatment processes. The solid waste management system needs to be modified and improved to make it compatible with the requirements of BT covering source separation collection of solid waste. Otherwise, the applicability will be limited to highly organic and homogenous waste streams like Market wastes.

Sanitary landfill
(Bioreactor Landfill)

Landfills have evolved from a long tradition of land disposal of wastes, dating back to prehistoric times. It provide for the environmentally sound disposal of waste that cannot be reduced, recycled, composted, combusted, or processed in some other manner. Landfills range in type from uncontrolled open dumps to sanitary and bioreactor landfills. For many years till date this land burial was accomplished by disposal in an open dump usually located in low lying lands, typically wet area because the land in these areas was the cheapest land available.

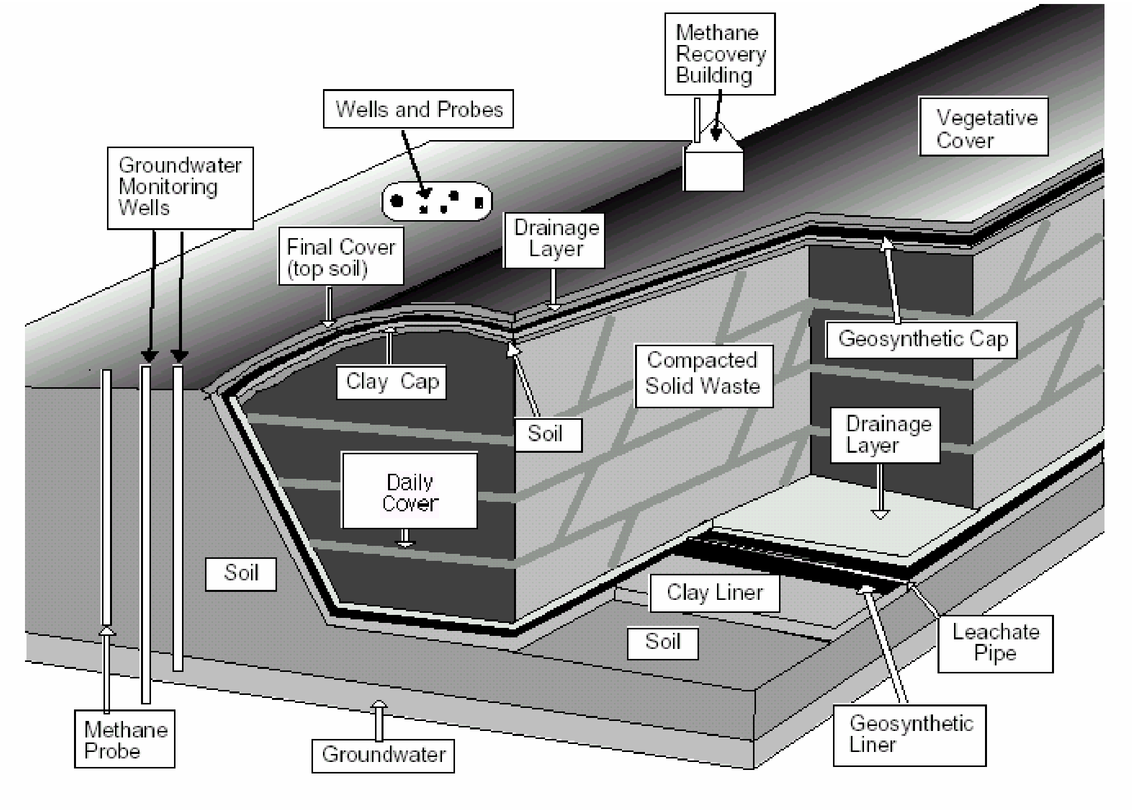
The open dumps frequently utilized burning of the residues in order to reduce volume. Odors arising from the decomposition of the wastes in the open dump and/or burning of the wastes, flies, rodents and other vermin, blowing papers, etc., led to the development of what is now called as the sanitary landfill.

Description of Landfill Technology

A sanitary landfill includes provisions for leachate management and the possible collection of landfill gas and its potential use as an energy source. It is based on the concept of isolating the landfilled wastes from the environment until the wastes are stabilized and rendered innocuous as much as possible through the biological, chemical and physical processes of nature.

Essentially the landfill design should incorporate the following components as depicted in **Figure 1**.

- The **liner system** at the base and sides of the landfill prevents migration of leachate or gas to the surrounding environment.
- The leachate collection and treatment system collects and extracts leachate from within and from the base of the landfill and treats to meet regulatory requirements.
- The final cover of the landfill enhances surface drainage, prevents infiltration of water and supports surface vegetation.
- The surface water drainage system collects and removes all surface runoff from the landfill site.
- The environmental monitoring system periodically collects and analyses air, surface water, soil and ground water samples around the landfill site.



Source: P. O'Leary and P. Walsh, University of Wisconsin-Madison Solid and Hazardous Waste Education Center, reprinted from *Waste Age* 1991-1992

Figure 7: **Cross Section of a Sanitary Landfill**

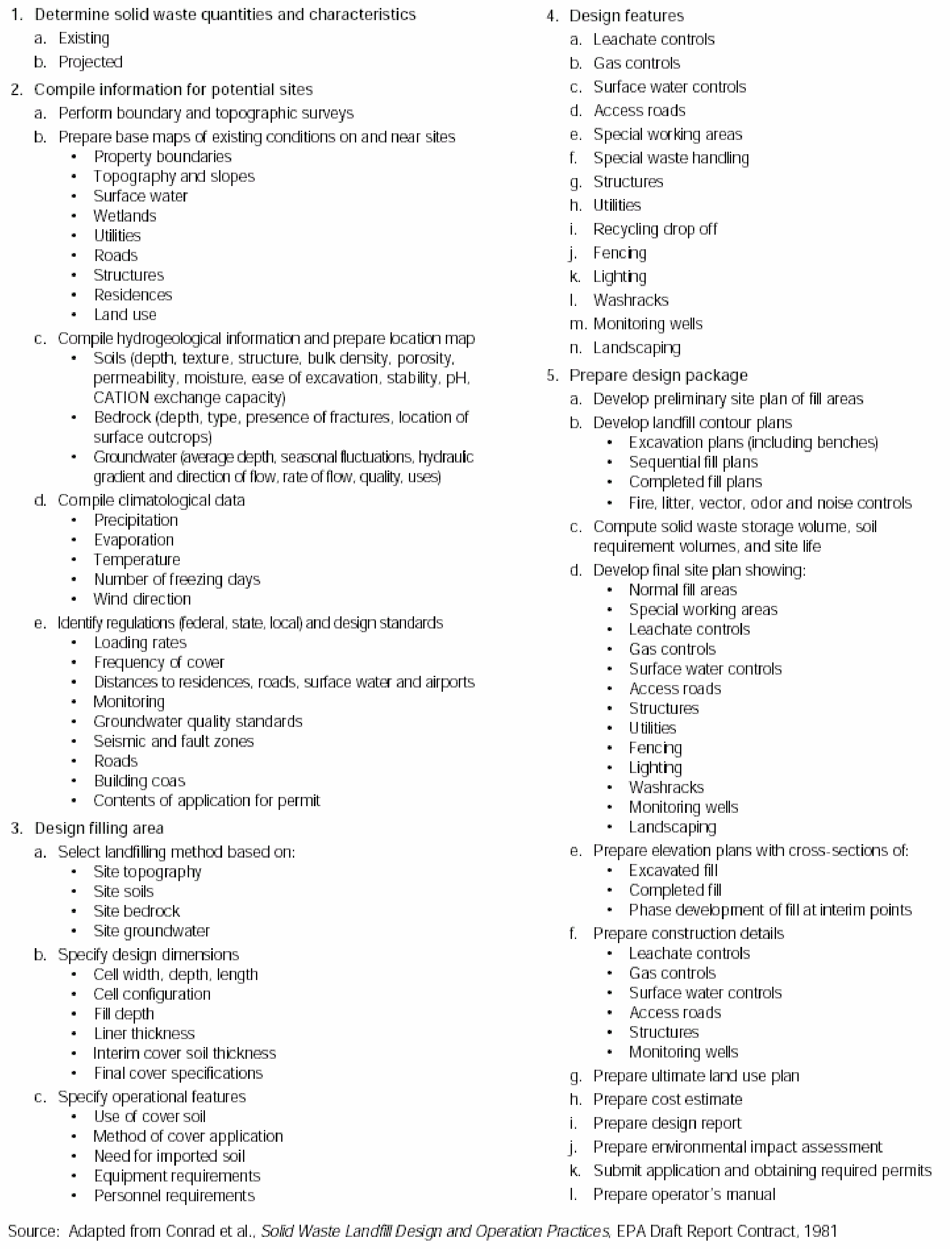
The main differences among the landfills involve the degree of isolation, the means of accomplishing it and optimizing the landfill reactions **(Table 1)**. The steps involved in the landfill design as presented on **Table 2** indicate its complexity.

Table 2: Types of Landfills

Type	Engineering measures	Leachate management	Landfill Gas Management	Operation Measures
Open Dumps	None	Unrestricted contaminant release	None	Few, scavenging
Controlled Dump	None	Unrestricted Contaminant release	None	Registration and placement/ compaction of waste
Engineered Landfill	Infrastructure and liner in place	Containment and some level of leachate management	Passive ventilation or flaring	Registration and placement/ compaction of waste; uses daily soil cover
Sanitary	Proper siting,	Containment and	Flaring	Registration and

Type	Engineering measures	Leachate management	Landfill Gas Management	Operation Measures
Landfill	infrastructure; liner and leachate treatment in place	leachate treatment (often biological and physico-chemical treatment)		placement/ compaction of waste; uses daily of soil cover, Measures for final top cover
Controlled Contaminant Release Landfill	Proper siting, infrastructure, with low-permeability liner in place. Potentially low-permeability final top cover	Controlled release of leachate into the environment, based on assessment and proper siting	Flaring or passive ventilation through top cover	Registration and placement/ compaction of waste, uses daily soil cover. Measures for final top cover
Landfill Bioreactor	Proper siting, infrastructure, liner and leachate recirculation / generation system	Controlled recirculation of leachates for enhanced degradation and stabilization of wastes and leachates	Landfill Gas recovery	Registration and placement/ compaction/ daily cover/ closure/ mining and material recovery

Table 3: Steps in Landfill Design



1. Determine solid waste quantities and characteristics
    a. Existing
    b. Projected
2. Compile information for potential sites
    a. Perform boundary and topographic surveys
    b. Prepare base maps of existing conditions on and near sites
        - Property boundaries
        - Topography and slopes
        - Surface water
        - Wetlands
        - Utilities
        - Roads
        - Structures
        - Residences
        - Land use
    c. Compile hydrogeological information and prepare location map
        - Soils (depth, texture, structure, bulk density, porosity, permeability, moisture, ease of excavation, stability, pH, CATION exchange capacity)
        - Bedrock (depth, type, presence of fractures, location of surface outcrops)
        - Groundwater (average depth, seasonal fluctuations, hydraulic gradient and direction of flow, rate of flow, quality, uses)
    d. Compile climatological data
        - Precipitation
        - Evaporation
        - Temperature
        - Number of freezing days
        - Wind direction
    e. Identify regulations (federal, state, local) and design standards
        - Loading rates
        - Frequency of cover
        - Distances to residences, roads, surface water and airports
        - Monitoring
        - Groundwater quality standards
        - Seismic and fault zones
        - Roads
        - Building coas
        - Contents of application for permit
3. Design filling area
    a. Select landfilling method based on:
        - Site topography
        - Site soils
        - Site bedrock
        - Site groundwater
    b. Specify design dimensions
        - Cell width, depth, length
        - Cell configuration
        - Fill depth
        - Liner thickness
        - Interim cover soil thickness
        - Final cover specifications
    c. Specify operational features
        - Use of cover soil
        - Method of cover application
        - Need for imported soil
        - Equipment requirements
        - Personnel requirements
4. Design features
    a. Leachate controls
    b. Gas controls
    c. Surface water controls
    d. Access roads
    e. Special working areas
    f. Special waste handling
    g. Structures
    h. Utilities
    i. Recycling drop off
    j. Fencing
    k. Lighting
    l. Washracks
    m. Monitoring wells
    n. Landscaping
5. Prepare design package
    a. Develop preliminary site plan of fill areas
    b. Develop landfill contour plans
        - Excavation plans (including benches)
        - Sequential fill plans
        - Completed fill plans
        - Fire, litter, vector, odor and noise controls
    c. Compute solid waste storage volume, soil requirement volumes, and site life
    d. Develop final site plan showing:
        - Normal fill areas
        - Special working areas
        - Leachate controls
        - Gas controls
        - Surface water controls
        - Access roads
        - Structures
        - Utilities
        - Fencing
        - Lighting
        - Washracks
        - Monitoring wells
        - Landscaping
    e. Prepare elevation plans with cross-sections of:
        - Excavated fill
        - Completed fill
        - Phase development of fill at interim points
    f. Prepare construction details
        - Leachate controls
        - Gas controls
        - Surface water controls
        - Access roads
        - Structures
        - Monitoring wells
    g. Prepare ultimate land use plan
    h. Prepare cost estimate
    i. Prepare design report
    j. Prepare environmental impact assessment
    k. Submit application and obtaining required permits
    l. Prepare operator's manual

Source: Adapted from Conrad et al., *Solid Waste Landfill Design and Operation Practices*, EPA Draft Report Contract, 1981

A bioreactor landfill (**Figure 8**) is a wet landfill designed and operated with the objective of converting and stabilising biodegradable organic components of the waste within a reasonable time frame by enhancing the microbiological decomposition processes. The technology significantly increases the extent of waste decomposition, conversion rates and process effectiveness over what would otherwise occur in a conventional wet landfill. Stabilisation in this context means that landfill gas and leachate emissions are managed within one generation (twenty to thirty years) and that any failure of the containment system after this time would not result in environmental pollution. There is better energy recovery including increased total gas available for energy use and increased green house reduction from reduced emissions and increase in fossil fuel offsets. These factors lead to increased community acceptance of this waste technology.

Management of a bioreactor landfill requires a different operating protocol to conventional landfills. Liquid addition and recirculation is the single most important operational variable to enhance the microbiological decomposition processes. Other strategies can also be used to optimise the stabilization process, including waste shredding, pH adjustment, nutrient addition and temperature management.

An additional advantage of both of the Bioreactor landfill designs is that it allow for the possibility of landfill mining. This would occur after the waste had stabilized and would allow the recovery of reusable materials and landfill space. The degraded organic fraction could be used as soil conditioner, and other materials such as glass and metals could be separated for recycling. This removal would free up the space previously occupied by this waste and allow for new waste to be deposited. This approach would also allow for the periodic inspection of the landfill liner system to ensure that it is still functioning properly and allow for repairs to be made if necessary. The improved liner performance would mean greater protection for the environment surrounding the landfill.

The main problems in achieving the potential benefits promised by bioreactor technology are that the nature of waste and existing landfill management practices both result in barriers to water contacting and moving uniformly through the waste. Injection and drainage systems are prone to biochemical fouling and the large volume of leachate required for flushing will ultimately require treatment and disposal.

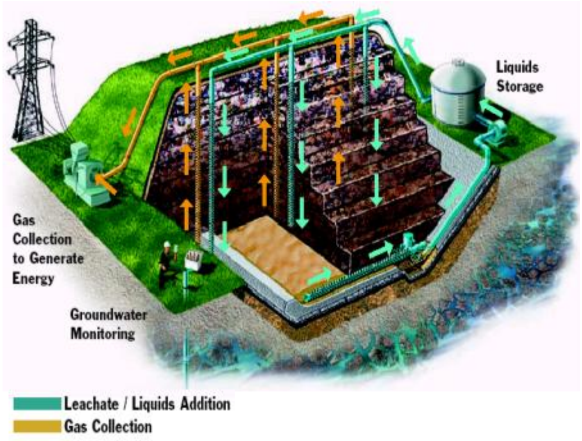


Figure 8: Bioreactor Landfill

Source: www.wm.com

Landfill technology is based on anaerobic decomposition, which depends on hydrolysis (breakdown of complex organics to monomers), acidification (acid formation) and methanogenisis (methane and CO_2 formation) phases. Conventional landfill technology has evolved over time beyond simply filling an excavated hole. Landfills now utilise a liner or a natural geological barrier beneath the waste, aimed at water protection, and improved local environmental amenity. Composite liners consisting of plastic membranes placed directly on top of a clay liner are not uncommon. Landfill gas is usually collected from large-scale developments by a piped collection system. Gas may be combusted to convert methane to carbon dioxide, either in flares or in engines that recover useable energy.

An important issue with conventional landfills is the extended period over which biodegradation of waste occurs, and hence the time span to reach stabilisation and negligible risk to the environment. This extended life means that leachate and landfill gas emissions must be collected and treated for decades after the closure of the facility. The technology is developed to a mature stage. Being largely a civil engineering operation the operational reliability of a landfill is impacted by factors such as inclement weather, or waste handling issues such as fires. Well operated landfills have measures in place to deal with these issues and have minimal downtime, so operational reliability is generally good.

Landfills are able to receive a wide range of non-hazardous wastes if operated with appropriate environmental controls such as liners and/or natural barriers, daily compaction and covering of waste and leachate and gas collection. The flexibility of waste input quantity is similarly high and as most of the operational equipment at landfills is mobile plant, there is high flexibility adapt to a wide range of incoming waste flows.

Landfills rate poor in terms of resource conservation, as very little of the resource contained in the waste is recovered. Energy balance of landfills is poor as relatively little of the energy contained in the waste is recovered from the landfill gas. The solid residues remaining after landfilling waste are very high, as they are themselves the ultimate destination of any residual solid waste in the waste management system. Some breakdown of the solid material into either the leachate or landfill gas, but a high proportion of the waste mass will remain in the landfill.

The greenhouse gas emissions from landfill are high. These emissions can be reduced by burning the methane to carbon dioxide, which reduces its greenhouse impact by a factor of 21. For larger landfills energy recovery is economic, and if electricity is produced it can be accredited as a "green power" generator. It has been claimed that as most of the carbon in the biomass remains in the waste and is not released in the landfill gas, landfills act as a carbon sink. However, as methane is a potent landfill gas and is never totally captured, landfills retain an overall negative greenhouse gas impact.

There is an environmental risk from leachate emissions, arising from contaminated water generated from surface or groundwater contacting the landfilled wastes or from the breakdown of the wastes. With modern leachate barriers and collection systems this is largely prevented from polluting the environment. Another potential source of water emissions is turbid stormwater that can be generated from a landfill facility due to a landfill being an earthworks site.

The un-vegetated and unsealed areas such as new disposal cells, recently completed cells, stockpiled soil and roads have a high potential to release sediments into storm water, and significant sedimentation and erosion controls have to be constructed to minimize this risk. Significant air emissions can be generated from the degradation of biodegradable waste within landfill facilities.

Overall, the risk of emission is moderate and the capacity of collection systems to capture emissions is moderate.

Public perception and confidence in landfilling varies with proximity to the operations. Protests in about proposed siting of new landfills indicate considerable displeasure when local communities are faced with the prospect of landfill impacts including traffic, vermin and odours. Noise emissions can be reduced through fitting and maintaining silencing on equipment, and with noise mounds and separation distanced between active areas and sensitive receptors. Large landfill sites will inevitably lead to noticeable odours in the adjacent area due to the volume of waste being deposited in the open, despite best practice operations. Dust emissions are related to operational practices at the site, and can be controlled through normal civil works practices of watering roads, providing windbreaks and reducing traffic speeds. The visual impact of landfills is significant as they cover a large area of land, although screening mounds and vegetation (that often double as noise barriers) can reduce this impact.

The benefits of the bioreactor landfill features are yet to be fully quantified and demonstrated. A landfill adopting bioreactor technology would may generate enhanced flows of leachate and landfill gas, and the collection and treatment systems would have to be capable of handling this increased load.

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ANNEXURE C

Description of Physical Processing Technologies – Refuse Derived Fuel/Pelletisation Process

REFUSE DERIVED FUEL

The term "refuse-derived fuel" (RDF) describes MSW that has been processed to a fairly uniform fuel for combustion in dedicated WTE plants or as complementary fuel in coal-fired power plants. The processing generally entails separation of inert materials through source reduction, and pelletizing. This allows for the removal of both recyclables and hazardous materials. The densified material can be easily transported, stored and combusted than raw MSW. Also, RDF can be produced on a small scale at several locations and then transported and used in large WTE plant. In the United States, much of the original impetus for Refuse-Derived Fuel (RDF) was to produce a fuel that could be co-fired with coal in existing utility power plant boilers. However, a range of mechanical and combustion problems (ash slagging, boiler tube corrosion, etc.) have limited the adoption of this technology.Wide adoption of RDF technologies has been hampered by the difficulties of processing a highly non-homogeneous material; also the use of RDF as a coal substitute requires modern gas control equipment that is not available at many coal-fired power plants.

Basically, RDF systems (**Figure 9**) are used to separate MSW into combustible and non-combustible fractions. The combustible material is called RDF and can be used in boilers. The MSW receiving facility includes an enclosed tipping floor called municipal waste receiving area, with a storage capacity equal to about two days of typical waste deliveries. The sorted MSW is then fed to either of the two equal capacity processing lines. Each processing line includes primary and secondary trommel screens, three stages of magnetic separation, eddy current separation, a glass recovery system, and a shredder. Due to reduction in fuel particle size and reduction in non-combustible material, RDF fuels are more homogeneous and easier to burn than the MSW feedstock. RDF has been successfully burned in a variety of stroker boilers and in suspension as a stand-alone fuel in bubbling and circulating fluidized bed combustion technology boilers. It needs lower excess air and hence works at better efficiency. Also, handling is easier since non-combustibles have been already removed. The RDF burning technology includes spreader stroker fired boiler, suspension fired boilers, fluidized bed units, and cyclone furnace units.

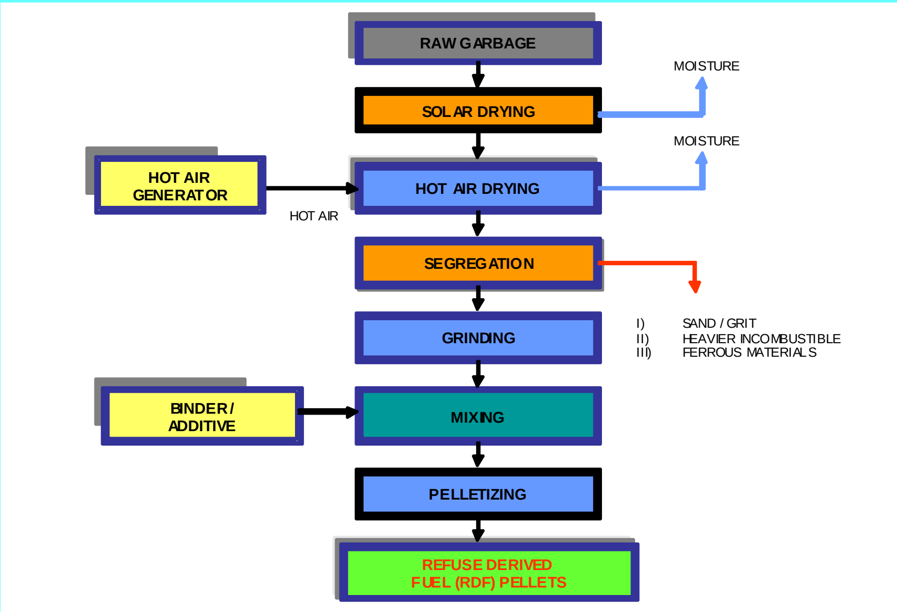

Figure 9: RDF Process Flow Diagram

There are two primary types of RDF systems in operation: the shred-and-burn systems with minimal processing and removal of non-combustibles, and simplified process systems that remove a significant portion of the noncombustible. Each of these systems uses a dedicated combustor to fire the RDF to generate steam. Shred and burn systems are the simplest form of RDF production. The process system typically consists of shredding the municipal solid waste to the desired particle size, magnetic removal of ferrous metal, with the remaining portion delivered to the combustor. There is no attempt to remove other noncombustible materials in the municipal solid waste before combustion. The municipal solid waste is shredded to a particle size that allows effective feeding to the combustor. Most systems operate the process system continuously, i.e., there is minimal RDF storage before being fed to the combustor. This technology involves various processes to improve physical and chemical properties of solid waste.

One way to increase the efficiency of MSW combustion is to mix the refuse with a higher caloric value/ton fuel or waste stream. In addition to coal, mixing or co-firing residential MSW with higher energy content agricultural or industrial-processing wastes will create a better fuel. This has been considered in a number of developing countries, including India. The agro-industrial and industrial waste products most often mentioned are rice husks and sawdust. Co-firing of MSW with agricultural or industrial wastes offers several advantages. First, it raises the energy content of the residential wastes, creating a fuel more readily used as a feedstock for existing combustion technologies (since these are normally designed for the higher caloric value of MSW in industrial countries). For example, rice husks have a caloric value of 14,421–14,886 kJ/kg (6,200–6,400 BTU/lb), double or triple the energy content of typical MSW. While rice husks have particular combustion problems due to the high silica content of the resulting ash, systems for burning them are readily available in all the nations with a substantial rice industry. Sawdust, particularly from woodworking industries, has an even higher caloric value than rice hulls: 13,956–17,445 kJ/kg (6,000–7,500 BTU/lb) and a lower moisture content, making it an ideal boiler fuel. Second, co-firing will reduce the volume of two waste streams headed for the landfill. It may also help create a large enough volume of total wastes to allow economies of scale and efficiency that neither the industrial complex or the urban waste district could achieve on its own.

There are currently more than 30 RDF plants or RDF processing plants currently operating in the United States, with a total installed capacity of 31,000 tons per day (TPD). Many of these U.S. plants were built in the period 1981–1990. These RDF plants typically process incoming MSW to shred it and then mechanically separate out metals, glass, and other non-combustible fractions of the waste stream, leaving just the shredded combustible portion of the waste. In the United States, RDF commonly has a caloric value of 13,956–17,445 kJ/kg (6,000–7,500 BTU/lb). For comparison purposes, U.S. sub-bituminous coal typically contains 19,306–26,749 kJ/kg (8,300–11,500 BTU/lb).

There are four RDF plants currently operational throughout the UK. The Byker refuse derived fuel plant in Newcastle has been treating waste since 1979. The plant can process about 50,000 tonnes of refuse per year. The waste is first sorted to remove any unwanted ash and wet material. The recyclable metals and glass are then removed. All the remaining waste has useful energy content and is then shredded and pelletised. Of the input, almost 27% of waste is produced into RDF pellets. The fuel pellets are then incinerated in a combined heat and power system and generates 2.3MW. Although the fuel quality is improved and makes for better more efficient combustion, the cost of the process is a major drawback.

Generally speaking, environmental impacts are related to dust, noise and odour plus waste water.

Incineration of RDF is considered waste incineration and must comply with normal standards for such facilities. However, a RDF system producing pellets will most likely have a reduced the flue gas emission compared to other types of waste incineration and the quality of the slag will be better compared to facilities without pre-sorting of the waste.

Presented below are few of the advantages and disadvantages of this technology.

- If produced, pellets are sufficiently dry for seasonal storage and can easily be handled and transported over longer distances, and therefore put on the market

- Pellets can be used as fuel in large industries, e.g. in cement kilns and other places where it can substitute coal, if proper permissions can be obtained and air emission limit values complied with

- The RDF facility itself is rather simple and may be applicable for Indian conditions. Most equipment may be purchased in India

- The internal energy consumption of the RDF facility is relatively high and the demand for maintenance of shredders, pelletiser and sorting equipment is substantial

- Alternatively, materials such as paper and plastics contained in the RDF fuel may have been recycled thus reducing the potential environmental and energy savings.

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