CHAPTER 15
ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE

15.1 INTRODUCTION

Municipal Solid Waste (MSW) contains organic as well as inorganic matter. The latent energy present in its organic fraction can be recovered for gainful utilisation through adoption of suitable Waste Processing and Treatment technologies. The recovery of energy from wastes also offers a few additional benefits as follows:

(i) The total quantity of waste gets reduced by nearly 60% to over 90%, depending upon the waste composition and the adopted technology;

(ii) Demand for land, which is already scarce in cities, for landfilling is reduced;

(iii) The cost of transportation of waste to far-away landfill sites also gets reduced proportionately; and

(iv) Net reduction in environmental pollution.

It is, therefore, only logical that, while every effort should be made in the first place to minimise generation of waste materials and to recycle and reuse them to the extent feasible, **the option of Energy Recovery from Wastes be also duly examined.** Wherever feasible, this option should be incorporated in the over-all scheme of Waste Management.

15.2 BASIC TECHNIQUES OF ENERGY RECOVERY

Energy can be recovered from the organic fraction of waste (biodegradable as well as non-biodegradable) basically through two methods as follows:

(i) **Thermo-chemical conversion** : This process entails thermal de-composition of organic matter to produce either heat energy or fuel oil or gas; and

(ii) **Bio-chemical conversion:** This process is based on enzymatic decomposition of organic matter by microbial action to produce methane gas or alcohol.

The Thermo-chemical conversion processes are useful for wastes containing high percentage of organic non-biodegradable matter and low moisture content.

The main technological options under this category include **Incineration and Pyrolysis/ Gasification.** The bio-chemical conversion processes, on the other hand, are preferred for wastes having high percentage of organic bio-degradable (putrescible) matter and high level of moisture/ water content, which aids microbial activity. The main technological options under this category is **Anaerobic Digestion,** also referred to as **Biomethanation**.

15.2.1 Parameters affecting Energy Recovery:

The main parameters which determine the potential of Recovery of Energy from Wastes (including MSW), are:

- Quantity of waste, and
- Physical and chemical characteristics (quality) of the waste.

The actual production of energy will depend upon specific treatment process employed, the selection of which is also critically dependent upon (apart from certain other factors described below) the above two parameters. Accurate information on the same, including % variations thereof with time (daily/ seasonal) is, therefore, of utmost importance.

The important **physical parameters** requiring consideration include:

- size of constituents
- density
- moisture content

Smaller size of the constituents aids in faster decomposition of the waste.

Wastes of the high density reflect a high proportion of biodegradable organic matter and moisture. Low density wastes, on the other hand, indicate a high proportion of paper, plastics and other combustibles.

High moisture content causes biodegradable waste fractions to decompose more rapidly than in dry conditions. It also makes the waste rather unsuitable for thermo-chemical conversion (incineration, pyrolysis/ gasification) for energy recovery as heat must first be supplied to remove moisture.

The important **chemical parameters** to be considered for determining the energy recovery potential and the suitability of waste treatment through bio-chemical or thermo-chemical conversion technologies include: -

- Volatile Solids
- Fixed Carbon content
- Inerts,
- Calorific Value
- C/N ratio (Carbon/Nitrogen ratio)
- toxicity

The desirable range of important waste parameters for technical viability of energy recovery through different treatment routes is given in the Table 15.1. The parameter values indicated therein only denote the desirable requirements for adoption of particular waste treatment method and do not necessarily pertain to wastes generated / collected and delivered at the waste treatment facility. In most cases the waste may need to be suitably *segregated/ processed/ mixed with suitable additives* at site before actual treatment to make it more compatible with the specific treatment method. This has to be assessed and ensured before hand. For example, in case of Anaerobic digestion, if the C/N ratio is less, high carbon content wastes (straw, paper etc.) may be added; if it is high, high nitrogen content wastes (sewage sludge, slaughter house waste etc.) may be added, to bring the C/N ratio within the desirable range.

Table 15.1 Desirable range of important waste parameters for technical viability of energy recovery:

Waste Treatment Method	Basic principle	Important Waste Parameters	Desirable Range*
<u>Thermo-chemical conversion</u> -Incineration -Pyrolysis -Gasification	Decomposition of organic matter by action of heat.	Moisture content Organic/ Volatile matter Fixed Carbon Total Inerts Calorific Value (Net Calorific Value)	< 45 % > 40 % < 15 % < 35 % >1200 k-cal/kg
<u>Bio-chemical conversion</u>	Decomposition of organic matter by microbial action.	Moisture content Organic /	>50 % > 40 %

-Anaerobic Digestion/ Bio-methanation		Volatile matter C/N ratio	 25-30

- Indicated values pertain to suitably segregated/ processed / mixed wastes and do not necessarily correspond to wastes as received at the treatment facility.

15.2.2 Assessment of Energy Recovery Potential

A rough assessment of the potential of recovery of energy from MSW through different treatment methods can be made from a knowledge of its calorific value and organic fraction, as under:

In thermo-chemical conversion all of the organic matter, biodegradable as well as non-biodegradable, contributes to the energy output :

Total waste quantity : W tonnes
Net Calorific Value : NCV k-cal/kg.
Energy recovery potential (kWh) = NCV x W x 1000/860 = 1.16 x NCV x W
Power generation potential (kW) = 1.16 x NCV x W/ 24 = 0.048 x NCV x W
Conversion Efficiency = 25%
Net power generation potential (kW) = 0.012 x NCV x W
If NCV = 1200 k-cal/kg., then
Net power generation potential (kW) = 14.4 x W

In bio-chemical conversion, only the biodegradable fraction of the organic matter can contribute to the energy output :

Total waste quantity: W (tonnes)
Total Organic / Volatile Solids: VS = 50 %, say
Organic bio-degradable fraction : approx. 66% of VS = 0.33 x W
Typical digestion efficiency = 60 %
Typical bio-gas yield: B (m^3)= 0.80 m^3 / kg. of VS destroyed
= 0.80 x 0.60 x 0.33 x W x1000 = 158.4 x W
Calorific Value of bio-gas = 5000 kcal/m^3 (typical)
Energy recovery potential (kWh) = B x 5000 / 860 = 921 x W
Power generation potential (kW) = 921 x W/ 24 = 38.4 x W
Typical Conversion Efficiency = 30%
Net power generation potential (kW) = 11.5 x W

In general, 100 tonnes of raw MSW with 50-60% organic matter can generate about 1- 1.5 Mega Watt power, depending upon the waste characteristics.

15.3 TECHNOLOGICAL OPTIONS

There are various technological options which can be employed for recovery of energy from MSW (Fig. 15.1). While some of these have already been applied at a large scale, some others are under advanced stages of development. A brief on these technologies is given below.

15.3.1 Anaerobic Digestion (AD)

In this process, also referred to as bio-methanation, the organic fraction of wastes is segregated and fed to a closed container (biogas digester) where, under anaerobic conditions, the organic wastes undergo bio-degradation producing methane-rich biogas and effluent/ sludge. The biogas production ranges from 50-150m^3/tonne of wastes, depending upon the composition of waste. The biogas can be utilised either for cooking/ heating applications, or through dual fuel or gas engines or gas / steam turbines for generating motive power or electricity. The sludge from anaerobic digestion, after stabilisation, can be used as a soil conditioner, or even sold as manure depending upon its composition, which is determined mainly by the composition of the input waste.

Fundamentally, the anaerobic digestion process can be divided into three stages with three distinct physiological groups of micro-organisms:

Stage I: It involves the fermentative bacteria, which include anaerobic and facultative micro-organisms. Complex organic materials, carbohydrates, proteins and lipids are hydrolyzed and fermented into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulfides.

Stage II: In this stage the acetogenic bacteria consume these primary products and produce hydrogen, carbon dioxide and acetic acid.

Stage III: It utilizes two distinct types of methanogenic bacteria. The first reduces carbon dioxide to methane, and the second decarboxylates acetic acid to methane and carbon dioxide.

Factors, which influence the Anaerobic Digestion process, are temperature, pH (Hydrogen Ion Concentration), nutrient concentration, loading rate, toxic compounds and mixing. For start-up a good innoculum such as digested sludge is required. A temperature of about 35-38^{0}C is generally considered optimal in mesophilic zone (20-45^{0}C) and higher gas production can be obtained under thermophillic temperature in the range of 45-60^{0}C. Provision of appropriate heating arrangements and insulation may become necessary in some parts of the country.

Anaerobic Digestion (AD) of MSW offers certain clear advantages over the option of Aerobic process, in terms of energy production/ consumption, compost quality and net environmental gains:

(i) AD process results in net production of energy.

(ii) The quality of the digested sludge (compost) is better as Nitrogen is not lost by oxidation.

(iii) Its totally enclosed system prevents escape of polluted air to atmosphere.

(iv) The net environmental gains are positive.

15.3.1.1 Main Steps in Anaerobic Treatment of MSW

Pre-treatment: to remove inerts and non-biodegradable materials, upgrade and homogenise the feedstock for digestion and to promote downstream treatment processes.

Anaerobic Digestion: and to produce biogas for energy to de-odorise, stabilise and disinfect the feedstock.

Post-Treatment: to complete the stabilisation of the digested material and to produce a refined product of suitable moisture content, particle size and physical structure for the proposed end-use as organic manure.

Effluent Treatment: to treat the liquid effluent to specified standards before final disposal.

15.3.1.2 Different Designs and Configurations of AD Systems

Different designs and configurations of AD systems have been developed by various companies to suit different total solid concentration in the feed and microbial activity i.e. single phase, bi-phasic, multi-phasic. The more popular ones are broadly categorised as low/ medium and high solids, two phase and leach bed systems.

(i) Low / Medium Solid Digestion Systems:

A large number of systems presently available worldwide for digestion of solid wastes are for low (< 10%) or medium (10-16%) solid concentrations. Some of these systems, when applied to MSW or Market Waste, require the use of water, sewage sludge or manure.

(ii) High Solid Continuous Digestion Systems:

These systems have been developed since the late eighties principally for the organic fraction of municipal solid waste but have also been extended to other industrial, market and agricultural wastes. The digestion occurs at solid content of 16% to 40%. These systems are referred to as 'Dry Digestion' or Anaerobic Composting when the solid concentration is in the range of 25-40% and free water content is low. Systems in this category vary widely in design and include both completely mixed and plug-flow systems.

(iii) Two Stage Digestion Systems:

In these systems the hydrolysis, acidogenesis and acetogenesis of the waste are carried out separately from the methanogenesis stage. Since each step is optimised separately, so that each of the reactions (i.e. acidogenesis, methanogenesis, etc.) is operated closer to its optimum, the rate of digestion is significantly increased. However, requirement of two reactors and more process controls may lead to higher capital costs and system complications.

(iv) Dry Batch Digestion/ Leach Bed Process:

This design concept is closest to the processes occurring naturally in a landfill. The reactor containing the organic material is inoculated with previously digested waste from another reactor, sealed and allowed to digest naturally. The leachate from the bottom of the reactor is re-circulated and heated, if required, to promote the degradation process.

In Leach Bed systems also referred to as SEBAC systems (Sequential Batch Anaerobic Composting) this leachate is treated in a wastewater digester prior to recirculation, and thus the solid phase digester essentially acts like a hydrolysis / acid forming stage of a two phase system. This approach has the distinct advantage of reduced materials handling but overall degradation of the organic matter can be lower than other systems.

A great deal of experience with biomethanation systems already exists in India, but a large part of this is related to farm-scale biogas plants and industrial effluents. There is little experience in the treatment of solid organic waste, except sewage sludge and animal manure. However, several schemes for bio-methanation of MSW and Vegetable Market Yard Wastes, are currently planned for some cities of the country.

15.3.2 Landfill Gas Recovery

The waste deposited in a landfill gets subjected, over a period of time, to anaerobic conditions and its organic fraction gets slowly volatilized and decomposed according to the process similar to that taking place in an Anaerobic Digestion system as detailed in the previous section. This leads to production of landfill gas containing about 45-55% methane, which can be recovered through a network of gas collection pipes and utilised as a source of energy.

Typically, production of landfill gas starts within a few months after disposal of the wastes and generally lasts for about ten years or even more depending upon mainly the composition of wastes and availability / distribution of moisture. The yearly gas production rates observed in full size sanitary Landfills in other countries range from 5-40 litre/kilogram. The MSW generated in major Indian cities is rich in organic matter and has the potential to generate about 15-25 l/kg of gas per year over its operative period.

The proportion of various constituent gases changes with time since the onset of decomposition (Fig.15.2). The gas tends to escape through the cracks and crevices in the deposited material unless suitable outlet is provided. It also moves by diffusion (concentration gradient) and convection (pressure gradient) mechanisms. Such lateral migration poses danger to adjoining structures and vegetation.

This gas can be recovered through an active system of vertical or horizontal wells, which are drilled into the waste where methane is being produced. Vertical wells are the most common type used and are located at the rate of about two wells per acre. The wells normally consist of perforated High Density Poly Ethylene or Poly Vinyl Chloride pipes of 50 to 300mm diameter surrounded by 300mm thickness of 25-35 mm size gravel. The gas wells are provided at the time of

filling of the landfill. The schematic of a typical gas well is given in Fig.15.3 and that of a typical closed Landfill in Fig.15.4. Generally depth of the gas well is 80% of the height of landfill. The wells are connected by a main collection Header and the gas is pumped out under negative pressure by a blower. The gas is passed through a moisture trap, gas cleaning unit, (containing activated alumina, silica gel or molecular sieves) a flame arrester, a non-return valve and gate value before its connection to the compressor (Fig. 15.5). Usually several gas wells are connected to a blower, though pumping from all the wells is not carried out simultaneously. A flare (open / enclosed flame) is provided to burn the gas when it can not be used.

Some studies have indicated out that out of the total theoretical quantity of CH_4, 20-25% can be recovered. Studies carried out for a few Indian cities indicate that the gas will continue to be generated over a period of 7-10 years. The wells and the compressor can be designed for capacities based on these values.

Not all landfill gas generated in the landfill can be collected; some of it will escape through the cover of even the most tightly constructed and collection system. Newer systems may be more efficient than the average system in operation today. A reasonable assumption for the gas collection efficiency for a properly planned gas collection system is 70 - 85%.

At locations, where the gas recovery may not be feasible, passive venting may be required to be carried out, by using a perimeter trench filled with gravel or rubble enclosed in wire mesh.

Landfill gas has a calorific value of around 4500 Kilo Calories per Cubic metre . It can be used as a good source of energy, either for direct thermal applications or for power generation. There are three primary approaches to using the landfill gas:

(a) direct use of the gas locally (either on-site or nearby):

(b) generation of electricity and distribution through the power grid; and

(c) injection into a gas distribution grid.

Direct use of the gas locally is often the simplest and most cost-effective approach. The medium quality gas can be used in a wide variety of ways, including; residential use (cooking, hot water heating, space heating); boiler fuel for district heating; and various industrial uses requiring process heat or steam (such as in cement manufacture, glass manufacture, and stone drying).

A description of the different techniques involved in the utilisation of landfill gas for power generation is given under **Section 15.4.**

15.3.2.1 Selection of Existing Landfill Sites for Gas Recovery

Before proceeding with Gas Recovery projects, it is necessary to ascertain which of the existing landfills or open dumps are likely to be large enough to warrant attention. Generally the sites considered suitable for recovery of energy are those having over one million tonnes of waste in place, a majority of which should be less than ten years old. Such sites are expected to generate enough gas to support a profitable gas recovery project over a number of years.

15.3.2.2 Assessment of Gas Production Potential

The current end potential future amount of methane gas that can be produced/ collected from any landfill site depends upon several factors including the amount of waste in place and its characteristics. The steps involved in estimating the gas production potential are as follows:

(i) Estimation of Total Waste Landfilled:

An estimate of the waste quantity at individual landfills and open dumps can be made from a knowledge of the following:

- Area, Depth, and Waste Density.
- Waste Records.
- Contour Plots.

If this data is not readily available for urban areas, a rough assessment of waste in place can be determined using the following data:

- urban populations;
- waste generation rate per person per year;
- fraction of waste landfilled; and
- the number of years landfilling has been taking place.

Using this information, the total amount of waste placed in all the landfills and large open dumps in the urban area is calculated as following :

Total Waste Landfilled (tonnes) = Urban Population **x** Waste Generation Rate (kg/person/year) **x** Fraction of Waste in Landfills or Open Dumps **x** Years of Landfilling **x** 0.001.

The average waste quantity in place at each site can then be arrived at by dividing the above total quantity by the total number of the sites, and adjusted further in proportion to their relative areas and/ or depths.

(ii) Assessment of Waste Characteristics:

Waste characteristics influence both the amount and the extent of gas production within landfills. Different countries and regions have MSW with widely differing compositions; wastes from developing countries, are generally high in food and yard wastes, whereas developed countries, especially North America, have a very high paper and cardboard content in their MSW. Landfills in developing countries will tend to produce gas quickly (completing methane production within 10-15 years) because putrescible material decomposes rapidly. Landfills with high paper and cardboard content will tend to produce methane for 20 years or more, at a lower rate.

If hazardous materials are mixed with the MSW, the recovered gas may contain trace quantities of hazardous chemicals, which would need to be removed from the gas prior to utilization. Higher gas purification requirements translate to higher costs.

If landfills or large open dumps primarily have large quantities of construction and demolition debris, they will not produce expected quantity of gas. Therefore, these sites may not be good candidates for energy recovery.

A knowledge of the waste types contained in a landfill site is, therefore, very important for fair assessment of the gas production potential. However, waste disposal records are often incomplete or nonexistent and specific studies have to be conducted for each specific site to assess the waste composition.

(iii) Methods of Gas Production Potential:

The following three methods are commonly used to estimate the gas production:

(a) Test Wells:

The most reliable method for estimating gas quantity, short of installing a full collection system, is to drill test wells and measure the gas collected from these wells. To be effective, the wells must be placed in representative locations within the site. Individual tests are performed at each well to measure gas flow and gas quality. The number of wells required to predict the quantity of landfill gas will depend upon factors such as, landfill size and waste homogeneity.

A general rule applied is to reduce the amount of gas collected by test wells by 50%. This is done because wastes at these sites are often loosely compacted or spread in varying amounts across the landfill. Also, gas migration at these sites is a common problem, which can escalate the gas collection figures. Furthermore, reducing the test estimates to half provides a conservative estimate of gas production, which is important for purposes of determining the size of the energy recovery system. Later, if it is established that the gas is being under-utilized, it is easy to supplement the collection system; however, the reverse is not possible.

An added benefit of this method is that the collected gas can be tested for quality as well as quantity. The gas should be analyzed for methane content as well as hydrocarbon, sulfur, particulate, and nitrogen content. This will help in designing the processing and energy recovery system.

(b) Rough Approximation:

The simplest method of estimating the gas yield from a landfill site is to assume that each tonne of waste will produce 6 m^3 of landfill gas per year. The procedure for approximating gas production is derived from the ratio of waste quantity to gas flow observed in the many diverse projects already in operation. It reflects the average landfill that is supporting an energy recovery project, and may not accurately account for the quality of waste, climate, and other characteristics present at a specific landfill.

This rough approximation method only requires knowledge of how much waste is in place at the target landfill or large open dump. The waste tonnage should be less than ten years old. Estimates from this approximation may however vary by as much as 50%. This rate of production can be sustained for 5 to 15 years, depending on the site. The Rough Approximation method produces the lowest estimates of gas recovery. As such, it will be the most conservative estimate for purposes of conducting the site assessment.

(c) Model Estimates:

Although test wells provide real data on the site's gas production rate at a particular time, models of gas production predict gas generation during the site filling period and after closure. These models typically require the period of landfilling, the amount of waste in place, and the types of waste in place as the minimum data. Two main models used for emissions estimating purposes are the "First Order Decay Model" and the "Waste In Place Model". The First Order Decay Model produces the highest estimates, but its estimates are very sensitive to the assumptions made about the timing of the waste disposal and gas recovery.

15.3.3 Incineration

It is the process of direct burning of wastes in the presence of excess air (oxygen) at temperatures of about 800^0C and above, liberating heat energy, inert gases and ash. Net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (fixed bed/ fluidised bed), etc. In practice, about 65 to 80 % of the energy content of the organic matter can be recovered as heat energy, which can be utilised either for direct thermal applications, or for producing power via steam turbine-generators (with typical conversion efficiency of about 30%).

The combustion temperatures of conventional incinerators fuelled only by wastes are about 760^o C in the furnace, , and in excess of 870^{o}C in the secondary combustion chamber. These temperatures are needed to avoid odour from incomplete combustion but are insufficient to burn or even melt glass. To avoid the deficiencies of conventional incinerators, some modern incinerators utilise higher temperatures of up to 1650^{o}C using supplementary fuel. These reduce waste volume by 97% and convert metal and glass to ash.

Wastes burned solely for volume reduction may not need any auxiliary fuel except for start-up. When the objective is steam production, supplementary fuel may have to be used with the pulverized refuse, because of the variable energy content of the waste or in the event that the quantity of waste available is insufficient.

While Incineration is extensively used as an important method of waste disposal, it is associated with some polluting discharges which are of environmental concern, although in varying degrees of severity. These can fortunately be effectively controlled by installing suitable pollution control devices and by suitable furnace construction and control of the combustion process. The various environmental concerns and pollution control measures are discussed in **Section 15.5**.

15.3.3.1 Basic Types of Incineration Plants

Both Stoker and Fluidised Bed type furnaces are used in incinerators. These are illustrated in Fig.15.6 and Fig.15.7. The modern municipal incinerators are usually of the continuously burning type, and may have “water wall” construction in the combustion chamber in place of the older, more common refractory lining. Corrosion of “water wall” units can, however, be a problem. Recent advancements include Twin Interchanging Fluidised Bed Combustor developed by a company in Japan, which is claimed to be capable of completely combusting wastes of low to high calorific values at very high overall efficiency (Fig.15.8).

Some basic types of Incineration Plants operating in the developed countries in the West and in Japan are as follows:

(i) Mass Burn:

About three-fourths of the waste-to-energy facilities in the U.S. and a few other countries are ‘mass burn’, where refuse is burned just as it is delivered to the plant, without processing or separation. These plants are sized to incinerate up to 3,000 tons of refuse per day and use two or more burners in a single plant. While facilities are sized according to the expected volume of waste, they are actually limited by the amount of heat produced when the garbage is burned. For example, if garbage burns hotter than it is expected to, less volume of material can be incinerated. Some mass burn plants remove metals from the ash for recycling. Mass burn plants have operated successfully in Europe for more than 100 years. A typical schematic diagram of such plants is given in Fig. 15.9.

(ii) Modular Combustion Units:

Modular incinerators are simply small ‘mass burn’ plants with capacity ranging from 25 to 300 tonnes per day. The boilers are built in a factory and shipped to the plant site, rather than being erected on the site, as is the case with larger plants. These facilities are often used in small communities.

(iii) Refuse-Derived Fuel (RDF) based Power Plants:

In an RDF plant, waste is processed before burning. Typically, the non-combustible items are removed, separating glass and metals for recycling.

The combustible waste is shredded into a smaller, more uniform particle size for burning. The RDF thus produced may be burned in boilers on-site, or it may be shipped to off-site boilers for energy conversion. If the RDF is to be used off-site, it is usually densified into **pellets** through the process of pelletisation.

Pelletisation involves segregation of the incoming waste into high and low calorific value materials and shredding them separately, to nearly uniform size. The different heaps of the shredded waste are then mixed together in suitable proportion and then solidified to produce **RDF pellets**. The calorific value of RDF pellets can be around 4000 kcal/ kg depending upon the percentage of organic matter in the waste, additives and binder materials used in the process, if any. Since pelletisation enriches the organic content of the waste through removal of inorganic materials and moisture, it can be very effective method for preparing an enriched fuel feed for other thermo-chemical processes like Pyrolysis/ Gasification, apart from Incineration. Additional advantage is that the pellets can be conveniently stored and transported.

RDF plants involve significantly more sorting and handling than Mass Burn facilities and therefore provide greater opportunity to remove environmentally harmful materials from the incoming waste prior to combustion. However, it is not possible to remove the harmful materials completely. Several years ago RDF was used mainly along with coal fired boilers but now, because of the stricter restrictions w.r.t. air emissions, it is usually burned in dedicated boilers designed and built specially for the RDF. In case of RDF Pellets too, it needs to be ensured that the pellets are not burned indiscriminately or in the open, but only in dedicated Incineration facilities or other well designed combustion systems, having all the necessary pollution control systems as described in **Section 15.5**.

15.3.3.2 Indian Scenario for Adoption of Incineration Technology

All sorts of waste materials are generated in the Indian cities as in other countries. However, in the absence of a well planned, scientific system of waste management (including waste segregation at source) and of any effective regulation and control of rag-picking, waste burning and waste recycling activity, the left-over waste at the dumping yards generally contains high percentage of inerts (>40%) and of puterscible organic matter (30-60%). It is common practice of adding the road sweepings to the dust bins. Papers and plastics are mostly picked up and only such fraction which is in an unrecoverable form, remains in the refuse. Paper normally constitutes 3-7% of refuse while the plastic, content is normally less than 1%. The calorific value on dry weight basis (High Calorific Value) varies between 800-1100 k-cal/kg. [**Tables 3.4 and 3.5 in Chapter 3**, refers]. Self sustaining combustion can not be obtained for such waste and auxiliary fuel will be required. Incineration, therefore, has not been preferred in India so far. The only incineration plant installed in the country at Timarpur, Delhi way back in the year 1990 has been lying inoperative due to mismatch between the available waste quality and plant design [The case study given in **Section 15.7** refers].

However, with the growing problems of waste management in the urban areas and the increasing awareness about the ill effects of the existing waste management practices on the public heath, the urgent need for improving the overall waste management system and adoption of advanced, scientific methods of waste disposal, including incineration, is imperative.

15.3.4 Pyrolysis/ Gasification

Pyrolysis is also refered to as destructive distillation or carbonization. It is the process of thermal decomposition of organic matter at high temperature (about 900^0C) in an inert (oxygen deficient) atmosphere or vacuum, producing a mixture of combustible Carbon Monoxide, Methane, Hydrogen, Ethane [CO, CH_4, H_2, C_2H_6] and non-combustible Carbon Dioxide, water, Nitrogen [CO_2, H_2O, N_2] gases, pyroligenous liquid, chemicals and charcoal. The pyroligenous liquid has high heat value and is a feasible substitute of industrial fuel oil. Amount of each end-product depends on the chemical composition of the organic matter and operating conditions. Quantity and chemical composition of each product changes with pyrolysis temperature, residence time, pressure, feed stock and other variables.

Gasification involves thermal decomposition of organic matter at high temperatures in presence of limited amounts of air/ oxygen, producing mainly a mixture of combustible and non-combustible gas (carbon Monoxide, Hydrogen and Carbon Dioxide). This process is similar to Pyrolysis, involving some secondary/ different high temperature (>1000^{o}C) chemistry which improves the heating value of gaseous output and increases the gaseous yield (mainly combustible gases $CO+H_2$) and lesser quantity of other residues. The gas can be cooled, cleaned and then utilized in IC engines to generate electricity.

Pyrolysis/ Gasification is already a proven method for homogenous organic matter like wood, pulp etc. and is now being recognised as an attractive option for MSW also. In these processes, besides net energy recovery, proper destruction of the waste is also ensured. The products are easy to store and handle. These processes are therefore being increasingly favoured in place of incineration.

15.3.4.1 Different Types of Pyrolysis/ Gasification Systems

The salient features of different types of Pyrolysis/ Gasification Systems so far developed are given below.

(i) Garrets Flash Pyrolysis Process:

This low temperature pyrolysis process has been developed by Garrett Research and Development Company. In a 4 tonnes per day pilot plant set up by the company at La Varne, California, the solid waste is initially coarse shredded to less than 50mm size, air classified to separate organics / inerts and dried through an air drier. The organic portion is then screened, passed through a hammer mill to reduce the particle size to less than 3mm and then pyrolysed in a reactor at atmospheric pressure. The proprietary heat exchange system enables pyrolytic conversion of the solid waste to a viscous oil at 500^{0}C. A schematic diagram of this system is given in Fig. 15.10.

(ii) Pyrolysis Process developed by Energy Research Centre of Bureau of Mines, Pittsburg:

This is a high temperature pyrolysis process to produce both fuel oil and fuel gas and has been investigated mainly at laboratory scale. The waste charge is heated in a furnace with nickel-chromium resistors to the desired temperature. The produced gases are cooled in an air trap where tar and heavy oil condense out. Uncondensed vapours pass through a series of water-cooled condensers where additional oil and aqueous liquors are condensed. The gases are then scrubbed in an electrostatic precipitator before further use. It is claimed that one tonne of dried solid waste produces 300-500 m^3 of gas, but the process is yet to be tested at full scale. A schematic diagram of this system is given in Fig.15.11.

(iii) Destrugas Gasification System:

In this system (Fig. 15.12) the raw solid waste is first subjected to shredding / size reduction in an enclosed shed. The air from this shed is taken up as intake air in the plant so as to avoid odour problems. The shredded waste is fed to retorts (heated indirectly by burning gas in a chamber enveloping it) through which it sinks under gravity and gets subjected to thermal decomposition. The produced gas is washed and most of it (85%) used for heating the retorts. The remaining 15% is available as fuel. The slag consists of mostly char.

15.3.4.2 Other Emerging Processes

(i) Slurry Carb Process:

This process has been developed by a company in USA to convert municipal solid waste into fuel oil. It is used in conjunction with a wet resource recovery process to separate out the recyclables. The received waste is first shredded and placed in an industrial pulper. The heavier and denser inorganic material sink to the bottom of the water-filled pulper from where it is easily removed. The remaining waste slurry (organic fraction) is subjected to violent pulping action, which further reduces the size of its constituents. The pulped organic waste is then subjected to high pressure and temperature whereby it undergoes thermal decomposition / **carbonisation** (slow pyrolysis) to fuel oil.

(ii) Plasma Pyrolysis Vitrification (PPV) / Plasma Arc Process:

This is an emerging technology utilising thermal decomposition of organic wastes for energy / resource recovery. The system basically uses a Plasma Reactor which houses one or more Plasma Arc Torches which generate, by application of high voltage between two electrodes, a high voltage discharge and consequently an extremely high temperature environment (between 5000- 14,000^{o}C. This hot plasma zone dissociates the molecules in any organic material into the individual elemental atoms while all the inorganic materials are simultaneously melted into molten lava.

The waste material is directly loaded into vacuum in a holding tank, pre-heated and fitted to a furnace where the volatile matter is gasified and fed directly into the plasma arc generator where it is pre-heated electrically and then passed through the plasma arc dissociating it into elemental stages. The gas output after scrubbing comprises mainly of CO and H_2. The liquefied produce is mainly methanol.

The entire process is claimed to safely treat any type of hazardous or non-hazardous materials. It has the advantage that the NO_X (oxides of Nitrogen) and SO_X (oxides of Sulphur) gases emissions do not occur in normal operation due to the lack of oxygen in the system.

Some US companies offering PPV technology are reported to be setting up some demonstration units based on this technology in Malaysia and Singapore.

15.3.5 Advantages and Disadvantages of Different Technological Options

The main advantages and disadvantages of the different technological options described above are given in Table 15.2.

Table 15.2 Advantages and Disadvantages of Different Technological Options:

Advantages	Disadvantages
Anaerobic Digestion Energy recovery with production of high grade soil conditioner. No power requirement unlike aerobic composting, where sieving and turning of waste pile for supply of oxygen is necessary Enclosed system enables all the gas produced to be collected for use. Controls Green House Gases emissions 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 systems are also available to take care of this. Unsuitable for wastes containing less organic matter Requires waste segregation for improving digestion efficiency.

Modular construction of plant and closed treatment needs less land area. Net positive environmental gains. Can be done at small-scale	
Landfill Gas Recovery Least cost option. The gas produced can be utilised for power generation or as domestic fuel for direct thermal applications.	Greatly polluted surface run-off during rainfall.
Highly skilled personnel not necessary. Natural resources are returned to soil and recycled. Can convert low lying marshy land to useful areas.	Soil / Groundwater acquifers may get contaminated by polluted leachate in the absence of proper leachate treatment system 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) Large land area requirement Significant transportation costs to faraway landfill sites may upset viability Cost of pre-treatment to upgrade the gas to pipeline quality and leachate treatment may be significant. Spontaneous ignition/explosions due to possible build up of methane concentrations in atmosphere
Incineration Most suitable for high Calorific Value waste, pathological wastes, etc.	Least suitable for aqueous/ high moisture content/ low Calorific Value and

Units with continuous feed and high through-put can be set up. Thermal Energy recovery for direct heating or power generation. Relatively noiseless and odourless. Low land area requirement.	chlorinated waste . Excessive moisture and inert content affects net energy recovery; auxiliary fuel support may be required to sustain combustion Concern for toxic metals that may concentrate in ash, emission of particulates, SOx, NOx, chlorinated compounds, ranging from HCl to Dioxins
Can be located within city limits, reducing the cost of waste transportation. Hygienic.	High Capital and O&M costs. Skilled personnel required. for O&M. Overall efficiency low for small power stations .
Pyrolysis/ Gasification Production of fuel gas/oil, which can be used for a variety of applications 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. High viscosity of pyrolysis oil may be problematic for its transportation & burning.

15.3.5 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/converted 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.

15.4 UTILISATION OF BIO-GAS

Main constituents of biogas are Methane (about 60%), Carbon Dioxide (about 40%) and small quantities of Ammonia and Hydrogen Sulphide. The Calorific Value of biogas is about 5000 kcal/m^3 and depends upon the methane percentage. The gas from landfills generally has a lower calorific value.

The biogas, by virtue of its high calorific value, has tremendous potential to be used as fuel for power generation through either IC Engines or Gas Turbines can be utilised for this purpose.

15.4.1 Local Gas Use

The simplest and most cost-effective option for use of landfill gas/ biogas is local gas use. This option requires that the gas be transported, typically by a dedicated pipeline, from the point of collection to the point(s) of gas use. If possible, a single point of use is preferred so that pipeline construction and operation costs can be minimized.

Prior to transporting the gas to the user, the gas must be cleaned to some extent. condensate and particulates are removed through a series of filters and/or driers. Following this minimal level of gas cleaning, gas quality of 35 to 50 percent methane is typically produced. This level of methane concentration is generally acceptable for use in a wide variety of equipment, including boilers and engines. Although the gas use equipment is usually designed to handle natural gas that is nearly 100 percent methane, the equipment can usually be adjusted easily to handle the gas with the lower methane content.

15.4.2 Pipeline Injection

Pipeline injection may be a suitable option if no local gas user is available. If a pipeline carrying medium quality gas is nearby, only minimal gas processing may be needed to prepare the gas for injection. Pipe line injection requires that the gas be compressed to the pipeline pressure.

- **Medium Quality Gas**. Medium quality gas will typically have an energy value that is the equivalent to landfill gas with a 50% methane concentration. Prior to injection, the gas must be processed so that it is dry and free of corrosive impurities. The extent of gas compression and the distance required to reach the pipeline are the main factors affecting the attractiveness of this option.

- **High Quality Gas**. For high-quality gas, most of the carbon dioxide and trace impurities must be removed from the recovered gas. This is a more difficult and hence more expensive process than removing other contaminants. Technologies for enriching the gas include pressure swing adsorption with carbon molecular sieves, amine scrubbing, and membranes and are described in **Section 15.4.4.** The schematic of a typical gas filter system is shown in Fig. 15.13.

15.4.3 Electricity Generation

Electricity can be generated for on-site or for distribution through the local electric power grid. Internal combustion engines (ICs) and Gas turbines are the most commonly used for landfill gas/ biogas-to-power generation projects.

- **Internal Combustion Engines**. Internal combustion engines are the most commonly used conversion technology in landfill gas applications. They are stationary engines, similar to conventional automobile engines, that can use medium quality gas to generate electricity. While they can range from 30 to 2000 kilowatts (kW), IC engines associated with landfills typically have capacities of several hundred kW.

  IC engines are a proven and cost-effective technology. Their flexibility, especially for small generating capacities, makes them the only electricity generating option for smaller landfills. At the start of a recovery project, a number of IC engines may be employed; they may then be phased out or moved to alternative utilization sites, as gas production drops.

IC engines have proven to be reliable and effective generating devices. However, the use of landfill gas in IC engines can cause corrosion due to the impurities in landfill gas. Impurities may include chlorinated hydrocarbons that can react chemically under the extreme heat and pressure of an IC engine. In addition, IC engines are relatively inflexible with regard to the airfuel ratio, which fluctuates with landfill gas quality. Some IC engines also produce significant NO_x emissions, although designs exist to reduce NO_x emissions.

- **Gas Turbines**. Gas turbines can use medium quality gas to generate power of sale to nearby users or electricity supply companies, or for on-site use. Gas turbines typically require higher gas flows than IC engines in order to be economically attractive, and have therefore been used at larger landfills; they are available in sizes from 500 kW to 10 MW, but are most useful for landfills when they are 2 to 4 MW (USEPA, 1993c). Also, gas turbines have significant parasitic loads; when idle (not producing power), gas turbines consume approximately the same amount of fuel as when generating power. Additionally, the gas must be compressed prior to use in the turbine.
- **Steam turbines**: In cases where extremely large gas flows are available, steam turbines can be used for power generation.
- **Fuel cells:** Fuel Cells, an emerging technology, are being tested with landfill gas. These units, expected to be produced in the 1 to 2 MW capacity range, are highly efficient with relatively low NO_x emissions. They operate by converting chemical energy into usable electric and heat energy.

15.4.4 Purification of Biogas

Most effluents and solid wastes contain sulphates, which give rise to presence of H_2S in the biogas. The engines to be fuelled by biogas, can tolerate H_2S content of up to 1000 ppm, beyond which the H_2S can cause rapid corrosion.

Although biogas generated from MSW is generally not expected to contain high percentage of H_2S, adequate arrangements for cleaning of the gas have to be made in case it is beyond 1000 ppm. Systems being used to remove H_2S from biogas are based on Chemical, Bio-chemical processes or physical processes, which are described below:

15.4.4.1 Chemical Processes

Chemical processes are based on absorption of H_2S by Alkali, Iron or Amines. The most widely used process for desulphurisation is the Amine process because it selectively absorbs H_2S from biogas and can be carried out at near atmospheric pressure. This can reduce the H_2S content to 800 ppm. The raw biogas is treated through an absorber column against tri-ethanol amine solution. The absorber has one or more packing beds of polypropylene rings to provide better contact between gas and the liquid media. Amine solution while reacting with biogas, gets saturated with H_2S and CO_2 and is sent to the stripper column wherein it gets regenerated by stripping off the H_2S and CO_2 by heating with steam. The sour gases are let off to a chimney. The regenerated amine is ready for reuse.

15.4.4.2 Bio-chemical Processes

These processes uses secondary treated effluent to clean the biogas. This effluent is sprayed from the top of the absorber columns while the raw biogas is blown in from the bottom. The effluent cleans the biogas and is then sent to a aeration tank where the H_2S is converted into sulphates. The effluent from this aeration tank is partly supplemented by fresh treated effluent and partly disposed off. The formation of elemental sulphur is outside the scrubber and therefore ensures availability of the scrubber without choking effect.

15.4.4.3 Summary of Gas Cleaning Methods

A summary of the different methods being used for purification of biogas is given in Table 15.3.

Table 15.3 Summary of Gas Cleaning Methods

Compound	**Process type**	**Process alternatives available**
H_2O	Adsorption	1. Silica gel 2. Molecular sieves, and Alumina
	Absorption	1. Ethylene glycol (at low temperature -20^{o}F) 2. Selexol
	Refrigeration	Chilling to -4^{o}F
Hydrocarbons	Adsorption	Activated carbon
	Absorption	1. Lean oil Absorption 2. Ethylene glycol, and 3. Selexol (All at low temperatures of -20^{o}F)
	Combination	Refrigeration with ethylene Glycol plus activated carbon Absorption
CO_2 and H_2S	Absorption	1. Organic solvents 2. Alkaline salt solutions 3. Alkanolamines
	Adsorption	1. Molecular sieves 2. Activated carbon
	Membrane separation	Hollow fiber membrane

	H_2S removal with Sulphur recovery	Bio-chemical process

15.5 ENVIRONMENTAL MANAGEMENT OF WASTE-TO-ENERGY PROJECTS

Any waste handling, treatment and disposal facility, either for energy/ resource recovery (including compost) or only for waste destruction, can be a source of environmental pollution (air/ ground/ water and land / visual/ noise/ odour pollution/ explosion), unless proper measures are taken in its design and operation. The major environmental concerns in case of the Waste-to-Energy facilities based on the established technologies of Incineration and Anaerobic Digestion, and the control measures necessary, are discussed in the next Section. The concerns/ measures for Incineration are, however, **generally also applicable** to the other waste processing/ treatment methods involving thermo-chemical treatment and those for Anaerobic Digestion, to the other waste processing/ treatment methods involving bio-chemical treatment (**including composting**).

15.5.1 Environmental Pollution Control (EPC) Measures for Incineration Plants

Incinerators burning MSW can produce a number of pollutants in the flue gas in varying concentration like carbon monoxide, sulfur dioxide, and particulate matter containing heavy metal compounds and dioxins. Many of these pollutants are formed as a result of incomplete/ partial combustion. That is, refuse that is not burned at high enough temperatures, for long enough or when too much or too little air has been added to the fire. The generation of these pollutants and their release into the atmosphere can be effectively reduced or prevented by incorporating a number of air pollution control devices and by proper operation of the WTE facility.

Concentrations of heavy metals in particulates, particularly lead, zinc, mercury and cadmium, may be significant and care must be exercised in their removal and disposal.

The most important of flue gas pollutants are sulphur dioxide (SO_2) and hydrogen chloride (HCl), the agents of acid rain. These may be eliminated by wet scrubbers. Hydrogen fluoride and oxides of nitrogen are also produced but are not normally a problem because of low concentrations. The emission of combustible, carbon-containing pollutants- dioxins and furans, is also of concern. The same can be controlled by optimizing the combustion process.

Other concerns related to incineration include the disposal of the liquid wastes from floor drainage, quench water, and scrubber effluents, and the problem of ash disposal in landfills because of heavy metal residues.

Following is a summary of the gaseous emission control devices now being used to remove pollutants from incinerator stack:

Dry Scrubbers

These "wash" particulate matter and gases from the air by passing them through a liquid. The scrubber removes acid gases by injecting a lime slurry (a watery mixture) into a reaction tower through which the gases flow. A dry powder containing salts is produced and collected alongwith the fly ash in an electrostatic precipitator or in filters and discharged alongwith the fly ash into the ash residue. The lime also causes small particles to stick together, forming larger particles that are easier to remove. Ash is stabilized by the addition of lime which enhances its natural alkalinity.

Electrostatic Precipitators (ESP)

These units use high voltage to negatively charge incoming dust particles, then the charged particles are collected on positively charged plates, ESPs - documented as removing 99.95% of Total Suspended Particulates (TSPs), including heavy metals - are very commonly used as WTE air pollution control devices. Nearly 43% of all existing facilities use this method to control air pollution.

Fabric Filters (Bag houses)

These consist of hundreds of long fabric bags made of heat-resistant material suspended in an enclosed housing which filters particles from the gas stream. Fabric filters are able to trap fine, inhalable particles (<10 microns) and can capture 99% of the particulates in the gas flow coming out of the scrubber, including condensed toxic organic and heavy metal compounds.

Stack Height

Stack height is an extra precaution taken to ensure that any remaining pollutants will not reach the ground in a concentrated area. When the gasses enter the stack they are quite clean due to the controls discussed above. Stacks being built today are 200-300 feet (60-90m)or more in height, twice as high as the stacks used on older municipal incinerators. Stack heights should be determined by calculating quantity of fuel used and considering local weather conditions also. Standard equations could be used for determining stack heights.

EPA, USA has developed strict air emission standards for incinerators. **CPCB has also stipulated certain standards for medical waste incinerators and these standards could be enforced till specific standards are evolved for MSW incinerators.**

The schematic of a typical flue-gas cleaning system of a modern MSW combustion facility is given in Fig. 15.14.

Dioxins and Furans:

In recent years, one group of chemical compounds, Polychlorinated dibenzofurans (PCDFs), commonly called dioxins and furans, has attracted special attention because of their toxicity, carcinogeecity and possible mutagenicity. These compounds are found in many foods - including fish, poultry and eggs - and occur in such common products as wood pulp and paper. About 75 different forms have been identified, of which five dioxins and seven furans are considered to be most toxic.

Fortunately, such compounds can be destroyed. It is claimed that by maintaining very high temperatures during the combustion process, waste-to-energy plants can eliminate virtually all of the dioxins that are produced. Also that a combination of scrubbers and fabric filtration systems can remove up to 99 percent of these large molecules. Activated carbon injection before the flue gas treatment has also proved to be effective. Activated carbon reactor and catalytic rectors can be used for advanced processing.

However, the dioxins and furans are the most controversial issues, and the mechanism of their production are not yet completely clarified and their removal methods are not yet completely established.

Water Pollution:

The liquid wastes of incineration - floor drainage, scrubber effluents and quench water - have the potential for the pollution of surface waters and aquifers, if they are discharged as waste effluents without treatment. **Faculty should make arrangements to meet the standards prescribed by the State Pollution Control Boards**.

Land Pollution:

Dry ash in the bottom residue and fly ash captured from flue gases in electrostatic precipitations or bag filters contain heavy metals and will pollute the land unless treated or disposed of at special hazardous waste landfills.

15.5.2 Environmental Pollution Control (EPC) Measures for Anaerobic Digestion Plants

The main points of concern relating to **Anaerobic Digestion** plants include:

- Biogas emissions/ leakage posing environmental and fire hazards.
- Gaseous exhaust from the power generating units which must be duly cleaned to meet specified standards for air emissions.
- Disposal of large quantities of water and of liquid sludge which can pose potential water pollution problem. While the liquid sludge can be used as rich organic manure, either directly or after drying, its quality needs to be duly ascertained for particular application. In case of use for food crops it needs to be to ensured that it is not contaminated by heavy metals/ toxic substances beyond permissible levels.

15.5.3 General Environmental Concerns and Control Measures

A summary of the general environmental concerns and control measures for waste processing, treatment and disposal facilities is given in Table 15.4.

15.6 PLANNING AND EXECUTION OF WASTE-TO-ENERGY PROJECTS

Any Waste-to-Energy project consist of several elements - collection/ availability of wastes, wastes treatment and recovery of energy, distribution and marketing of the end products, disposal of final rejects/ effluents, etc. If any of these elements malfunctions, smooth management of the project can not be ensured. A careful and proper advance planning is therefore very importance for the success of these projects.

Table 15.4 Summary of General Environmental Concerns and Control Measures for Waste Processing, Treatment and Disposal Facilities.

Waste treatment technology	Environmental concerns	Control measures

Thermo-chemical processes	Condensate from gas/ steam	Recovery, recycling in process/ treatment.
-do-	Residual inorganic material	Inert residual materials such as broken glass, crockery and rubble to landfill.
-do-	Gasifier char (a valuable source of plant nutrients). Incinerator ash	Leachability tests to determine soluble metal compounds. Contaminated char to be stabilised prior to disposal.
All power generation Facilities	Noise from gasifier and engines	To be enclosed in acoustic modules with noise attenuated to 75dB @ 1m from source. Plant to have adequate buffer space from nearest residential areas.
All incorporating wet separation processes	Contaminated water from separation process	Recovery, recycling in process/ treatment
All	Stormwater from site	If contaminated, diversion/storage for process use/ treatment to specified standard before discharge.
-do-	Wind blown rubbish	Mesh fences around facility with periodic cleaning of rubbish.
-do-	Odour from the waste storage / processing buildings	Air from these areas to be extracted and treated to destroy odour causing compounds prior to release to atmosphere.
-do-	Exhaust gas from combustion engines or	To be within limits prescribed by CPCB for industrial air

	process burners	emissions.
-do-	Flies and mosquitoes	All MSW received at the WTE site to be processed and disposed off within 10 hrs of their receipt.
-do-	Rats and Birds	MSW receival area to be cleaned daily. MSW storage area to be an enclosed/ sealed building and cleaned weekly.

15.6.1 Basic Factors in Planning and Execution

The important factors which need to be considered and taken into account while planning any Waste to Energy facility and for selecting most appropriate, techno-economically viable technology, are given below:

15.6.1.1 Cost of Collection & Transportation of Wastes

The logistics of waste collection/ segregation and its transport to plant site are of fundamental importance. Sufficient consideration should be given to the costs involved in the same. In the specific case of MSW, collection and transportation costs often account for the largest proportion of MSW treatment costs, which may be as high as 70% and may preclude consideration of certain technologies e.g. Sanitary Landfilling at faraway sites.

15.6.1.2 Scale of Treatment

The waste quantity available/ to be processed is another major factor requiring careful consideration. Large scale treatment would be advantageous for large cities where large waste quantities are discharged in limited area. Small scale treatment on the other hand may be more suitable for low discharge density/ small quantities of wastes to be treated. Such facilities will have the advantage that they can be operated easily and quickly. However, collection and transportation costs in this case (involving wide area) are bound to be higher than in the latter case involving a limited area, and a trade-off will be necessary.

15.6.1.3 Local Conditions/ Existing Waste Management Practices

The viability of any Waste to Energy Project, critically depends upon, inter-alia, an assured availability of the requisite quantities and quality of the waste. Implicit, therefore, will be the need to ensure proper linkages in waste management right from its generation at source to final disposal.

The waste management practices generally vary with: the local socio-economic and physical conditions, rates of waste generation, and wastes composition. The last two factors also determine the potential for energy recovery within the over all frame-work of the waste management system. The local socio-economic conditions and existing WM practices may, however, over-ride certain solutions which otherwise are techno-economically more viable. Conversely, there will be a need to improve the existing waste management practices/ local conditions to suit the selected technological option/ maximize energy recovery component.

For example, wastes of different qualities from different activities often get mixed up with the Urban Municipal waste stream. Some of these wastes have a very high percentage of organic matter and accordingly a high energy recovery potential. It should, therefore, be ensured that such wastes are collected and transported directly to the energy recovery facilities and not allowed to get mixed up with other waste streams with low energy recovery potential.

15.6.1.4 Physical and Chemical Characteristics of the Waste

A careful evaluation of percentage of bio-degradable/ combustible constituents/ moisture content of the waste and its chemical composition is necessary for selection of most appropriate technology.

Wastes from vegetable/ fruit yards and markets, agricultural and food processing units etc. contain high concentration of bio-degradable matter and are suitable for energy recovery through anaerobic de-composition. Solid wastes having a high proportion of paper and wood products, on the other hand, will be suitable for incineration.

The composite solid wastes in urban areas in India are characterized, in general, by low percentage of combustibles and high percentage of inorganic/ inerts and moisture and are not very suited for incineration. The waste is generally rich in bio-degradable matter and moisture content and can be treated anaerobically in Sanitary Landfills or Anaerobic Digesters for energy recovery.

In situations, where waste containing high percentage of combustibles and low percentage of inorganic/ inerts and moisture, is either available or can be ensured, through either adoption of effective waste segregation/ processing methods or in any other manner, the Incineration / Gasification / Pyrolysis options can be gainfully utilised.

15.6.1.5 Seasonal Fluctuations in Wastes Quantity & Quality

This is important as any imbalance between the availability of requisite quantity and quality of wastes and the energy demand/ utilization pattern may adversely affect the project's viability. In case of conversion to steam/ heat energy, it would be necessary to consume them in the vicinity of the plant as soon as produced. Otherwise, the technologies of transportable and storage type energy conversion viz. gasification/ pyrolysis (conversion to fuel oils), densification (conversion into fuel pellets) may be considered to tackle such imbalance.

15.6.1.6 Treatment/Disposal of Rejects/Effluents

The method of treatment and disposal of the final rejects/ effluents should be considered in advance. The utility of the same should also be considered as in case of anaerobic digestion, where about 70% of the input is discharged as sediment (digested sludge), but the same after being stabilized through aerobic treatment, can be used as a good fertilizer.

It should be borne in mind while adoption of any particular technology that MSW, though not classified as Hazardous or Toxic, may also contain some such waste component (solvents, paints, pesticides, sewage sludge, pathological wastes from hospitals, etc.). Proper Waste management requires that such waste materials are stored, collected, transported and disposed off separately, preferably after suitable treatment to render them innocuous and not mixed with the Urban Waste stream. The possibility, however, of Toxic & Hazardous wastes being present in the MSW, should be carefully examined and duly taken into consideration during their treatment/ processing and in the design of the WTE plants.

Plastic wastes may account for 1-10% of the total Municipal Solid Wastes. They are highly resistant to bio-degradation, which makes them objectionable for release to the environment and of special concern in waste management. Plastics have a high heating value making them very suitable for incineration. However, PVC when burnt, may, under certain conditions, produce dioxin and acid gas, which calls for adequate safety measures as already discussed in previous sections.

15.6.1.7 Energy End-Use

Effective marketability of end products (thermal energy/power/fuel oil/gas/pellets) will be a crucial factor determining the projects viability and needs to be tied-up in advance. In case of projects aimed at power generation, the availability of grid close to plant site would, of course, be necessary to enable wheeling of the generated power to third parties or its sale to utility.

15.6.1.8 Capital and Recurring Costs

These will be governed by, inter-alia, the Land area requirements and the auxiliary power/water requirements of the project besides availability of infrastructure and manpower with adequate expertise and skill for smooth operation and maintenance.

15.6.1.9 Environmental Impact

A relative assessment of different technological options from environmental angle is necessary keeping in view the existing regulatory standards. The basic approach adopted should be to promote environmentally sound waste disposal and treatment technologies and wherein energy recovery is only an additional benefit. **It should also be kept in view that a problem/ solution in waste disposal does not become a problem in air pollution or water pollution**.

In general, the ideal technology to choose should be the one which requires, per unit volume of the waste treated, the minimum space, generates the minimum rejects requiring further disposal and/ or effluents requiring least treatment before final usage on discharge, demands least O&M efforts on the part of user agency in terms of both O&M expenditure and manpower, has the best impact on minimizing environmental pollution, requires the least initial capital investment and, of course, recovers the maximum net energy. In practice, however, a trade-off between these aspects would have to be made and the decision based on techno-economic viability of any option at the specific site keeping in view the local conditions and the available physical and financial resources.

15.6.2 Scope of Feasibility Studies

The suggested scope of Feasibility Studies to be conducted for ascertaining the techno-economic viability of different waste treatment options is summarised below:

15.6.2.1 Quantity of Municipal Solid Waste Generated per day

- Per capita and total generation.
- Zone-wise quantity.

- Number of collection points along with quantity of waste available at each.

15.6.2.2 *Current Mechanism for Collection/ Transportation*

- Existing mode of collection
- Details of collection and dumping points, and waste quantities collected/ dumped per day at each point.
- Site maps showing the location of collection and disposal sites.

15.6.2.3 *Physical & Chemical Characteristics of Collected Waste*

- Size of constituents, density, moisture content, calorific value, ultimate/ proximate analysis, % of volatile solids & fixed carbon, etc.
- Sampling of waste to be over minimum period of 3 consequtive seasons.
- Sampling procedure to be as per BIS norms.

15.6.2.4 *Present Mode of Disposal*

- Burning/ composting/ other methods.
- Expenditure involved.

15.6.2.5 *Provisions in the Existing System for*

- Segregation of inert material
- Recycling
- Scientific disposal/ energy recovery
- Revenue generation

15.6.2.6 *Commitments/Arrangements of Concerned Municipality with Private Parties regarding Waste Collection/ Disposal , if any*

15.6.2.7 *Details About the Proposed Scheme of Energy Recovery*

- site details / suitability
- sizing of plant capacity
- estimated waste processing/ treatment capacity

- estimated energy recovery potential/ other by-products.
- assessment of alternative options/ technology selection;
- quantity & quality of final rejects to be disposed off & their disposal method;

15.6.2.8 Environmental Impact Assessment Analysis of the Selected Option

15.6.2.9 Energy End-Use & Revenue Generation

15.6.2.10 Cost Estimates

Capital cost, O&M costs including manpower,

Revenue, Cost benefit analysis, etc.

15.7 CASE STUDIES

Some Case Studies on specific projects on Energy Recovery from Municipal Solid Wastes in developed countries as well as India, are cited in the Annexure 15.1 to provide a brief over-view of the developments in the *Waste-to- Energy* sector across the world.

15.8 CONCLUSIONS

The different technologies for recovering useful energy from Municipal Solid Wastes already exist and are being extensively utilised in different countries for their multiple benefits. It is necessary for the success of these technologies in India to evolve an Integrated Waste Management system, coupled with necessary legislative and control measures. A detailed feasibility study needs to be conducted in each case, duly taking into account the available waste quantities and characteristics and the local conditions as well as relative assessment of the different waste disposal options. Suitable safeguards and pollution control measures further need to be incorporated in the design of each facility to fully comply with the environmental regulations and safeguard public heath. The Waste-to-Energy facilities, when set up with such consideration, can effectively bridge the gap between waste recycling, composting and landfilling, for tackling the increasing problems of waste disposal in the urban areas, in an environmentally benign manner, besides augmenting power generation in the country. Ministry of Non-Conventional Energy Sources is providing financial assistance for energy recovery projects given as per Annexure 15.2.