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Application of SWOT Analysis for the Selection of Technology for Processing and Disposal of MSW

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Abstract

Municipal solid waste management system cannot be made sustainable only with the technical end-of-pipe solutions but an integrated approach is necessary. The use of SWOT (strength & weakness and opportunity & threats) analysis technique for the selection of technology for processing and disposal of municipal solid waste will help to mitigate the uncertainties and minimise the business/project risk and will also help to identify the raw material feed mix, establish a raw material supply chain, identify the product mix and product market, business model & business risk. In this paper a systematic approach has been developed for the selection of right technology for the sustainable processing and disposal of municipal solid waste.

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*Keywords:Municipal Solid Waste * Anaerobic Digestion * Pyrolysis * Plasma Gasification * SWOT * Composting;*

1.0 Introduction

Municipal solid waste (MSW) consists of mainly renewable resources such as food, paper, and wood products; it also includes non-renewable materials derived from fossil fuels, such as tires and plastics etc. There are number of technologies by which major portion of MSW can be processed in an environment friendly manner for extraction of value from it. In fact, technologies are available which can convert virtually any type of waste into energy. Recycling, composting (Vermi and Windrow), waste to energy and landfill gas extraction are the basic technological form through which value can be extracted from the MSW. Technologies for waste to energy can be classified in to two types of chemical conversions ; i) Thermo chemical conversion-[Incineration or mass burn , Pyrolysis,

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Refused Derived Fuel (RDF), Plasma Gasification or other form] and ii)Bio-chemical conversion (Anaerobic digestion/ Bio-methanation or fermentation etc). But not all the technologies are suitable for everywhere. In many occasions, successful technologies in developed countries have failed in developing countries. Large-scale composting projects in Africa and Asia were too expensive and inappropriate to the local conditions. As a result, some facilities had been closed, others had been scaled down, and many operate below their planned capacities (Medina M, et al, WB Report 2009). Similar experiences with incinerators have been reported India too. In Delhi, incinerator built in 1999 has been failed due to very low calorific value of waste. Selection of right technology is crucial for the sustainability of the waste processing and disposal projects.

A technology sustainable at a place may not be sustainable at other place due to one or more reasons.Technical suitability depends on various factors like waste characteristics and quantity, climatic conditions, environmental rules and regulations of the place, availability of human resources etc. For the selection of right technology for processing and disposal of MSW, the strength & weakness and opportunity & threats (SWOT)of the external and internal factors of the waste processing and disposal project is required to be done. In this paper a systematic approach has been developed for the selection of right technology for processing and disposal of MSW.

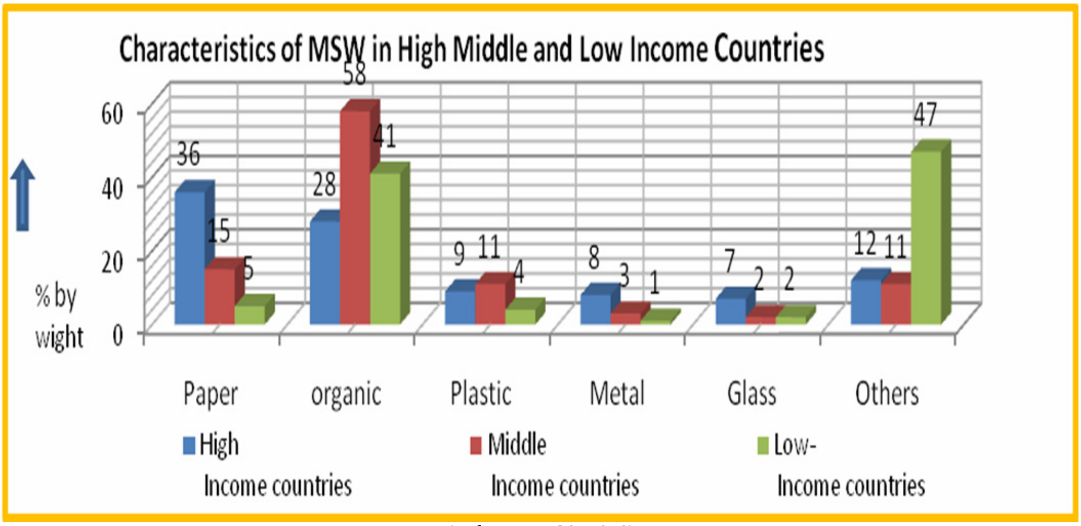
2.0 Objective

The objective of this work is to identify the method of selection of right technology for processing and disposal of municipal solid waste; which may eventually promote a sustainable waste management system.

3.0 Literature Survey

3.1 Socio Economic Factors for MSW Generation

There are major differences between the industrialized and developing countries in the field of solid waste management (SWM) system and solutions. The waste generation tends to go up as income increases. Cities of developed countries have higher waste generation rates than cities of developing countries. The average per capita waste generation rate in developed countries varies from 1.12 to 2.08 kg. per day where as in developing countries it is 0.40 to 0.66 kg. per capita per day(Dhokhikah Y 2012**)**. In the U.S waste generation rates is 2.10 kg per person per day (Municipal Solid Waste Generation, Recycling, and Disposal in the US: Facts and Figures for 2012, EPA, USA.) while the residents of Indian cities on an average generate 0.495 kg. per person per day (NEERI 2012) .



(Ref:- UNDESA, 2010)

Fig. 1.Characteristics of MSW in High and Low Income Countries

Moreover, there exist profound differences between developed and developing countries in terms of income, standard of living, consumption patterns and there by the MSW generation pattern and the characteristics differ substantially. Waste generated in developing countries contains a large percentage of organic materials, usually three times higher than that of developed countries (Figure 1).

3.2 Parameter of Waste Processing Technologies

3.2.1 Composting:

Composting is a controlled method of using microbial organisms to decompose the organic fraction of solid waste. Composting has the advantages of lower operational cost, no water pollution, lessened environmental pollution and beneficial use of end products (Airan et al 1980), composting can be done in aerobic condition and also in anaerobic condition.

3.2.1.1 Vermi Composting

a) Process Conditions: Vermi Composting requires semi decomposed or fermented organic matter feed to vermi at temperature of around average temperature of 27^0C. Worms are sensitive to variations in climate. Extreme temperatures and direct sunlight are not healthy for the worms. The optimal temperatures for vermin composting range from 12° C to 25° C (Waste Resource Conservation EPA, USA). The most common worms used in composting systems are redworms (Eiseniafoetida, Eiseniaandrei, and Lumbricusrubellus) but European nightcrawlers (Eiseniahortensis). These species feed most rapidly at temperatures of 15–25 °C . They can survive up to 10 °C. Temperatures above 30 °C may harm them. The substrate should always be moist & cooland humidity between 49 and 75%. Rainy days i.e. direct rains affect active life of worms thereby reducing production. Out of the two methods (viz., the pit method and the heap method) of vermin composting, the efficacy of the pit method of vermin composting is superior to the heap method in winter and summer, whereas the heap method is better in the rainy season (Jasem M , 2008).

3.2.1.2 Windrow Composting:

a) Process Conditions: Windrow composting is best suitable for the tropical climate where the temperature remains moderate with mean minimum and maximum temperature ranging between 20^0C and 35^0C respectively (Waste Resource Conservation EPA, USA). Windrow composting can be proceed at any moisture content between 30 and 90%, if adequate aeration is provided. High moisture displaces air from the interstices between the particles. Optimum moisture content is 45 to 50%. moisture causes foul odour, increased period of decomposition, files menace & leachate generation (Henry H, US Dept. of Agriculture). The windrows should be allowed to ferment at thermophilic temperature range to 60^0 to 65^0 C for one week. This is the phase where waste stabilization and pathogen destruction are most effective. Due to thermophilic temperature, there is moisture loss, which should be maintained at around 40% (+/-) 5% all the time. Windrow composting can work in cold climates. Often the outside of the pile might freeze, but in its core, a windrow can reach 60° C (Waste Resource Conservation EPA, USA). In a warm, arid climate, windrows are required to be covered or placed under a shelter to prevent water from evaporating. Ideal C : N Ratio for composting is 20-30 : 1 and the rate of decomposition depends on relative amounts of carbon and nitrogen present . Additions of ‘N’ rich materials such as cowdung slurry are beneficial. Lower C : N. ratio will retard decomposition and increase nitrogen loss. Carbon and phosphorus ratio should be 100 : 1 for microbial growth and digestion (Waste Resource Conservation EPA, USA).

Product Output from Composting: In composting of MSW, the biodegradable fraction of municipal solid waste (MSW) decomposes by aerobic or anaerobic condition and the product is either disposed of by land application or marketed as compost, provided the feed material is free from toxic components. This method entails the most appropriate reuse / recycle of solid wastes by transforming them into fertilizers / soil conditioner. Composting has the advantages of lower operational cost (Airan et al, 1980).

3.2.1.3 Environmental Issues Relating to Composting:

Leachate is a liquid released during the composting process. This can contaminate local ground-water and surface-water supplies and should be collected and treated. In addition, windrow composting is a large scale operation and might be subject to regulatory enforcement. The main concern of using compost from MSW as soil conditioner is the content of metals that can result in increased heavy metal content of crops. Furthermore these metals and excess nutrients can move through the soil profile into groundwater. Municipal solid waste compost may have high salt concentrations, which can inhibit plant growth and negatively affect soil structure (Hargreaves J , 2008).

3.2.2 Anaerobic Digestion (AD):

a) Process conditions: Anaerobic digestion (AD) of organic fraction of municipal solid waste (OFMSW) is not very high technology oriented and can be adopted in very small to large scale processing plants. AD plant does not occupy large area, its O&M cost is very low and can be certified under CDM (Clean Development Mechanism), it does not pollute environment, it can be located almost everywhere in a city.

a) Temperature: The rate of anaerobic digestion of organic waste is influenced by temperature. Digester operations fall into two temperature ranges :mesophillic and thermophillic . Thermophillic digesters are operated in the range of 38^0 C to 60^0C with the optimum at about 54^0C while mesophillic digestion occurs between 26^0 C to 42^0 C with the optimum at approximately 35^0 C. Although thermophillic digestion usually results in higher gas yeilds and production rates, it is rarely applied to the municipal waste digestion facilities primarily due to high cost of heating.
Ranges of temperature for different stages of AD are hydrolysis and Acidogenesis / Acetogenesis 25-35°C *(GregorD et.al 2012),* MethanogenesisThermophilic range- 50–60^0 C, Mesophilic range- 20–40^0 C and Psychrophilic range 10–20^0 C *(Battistoni P et al., 2000).* Gas from thermophilic digesters contains slightly higher methane percentage (67% CH_4) than digester gas from mesophilic digesters (64% CH_4).

Table 1: Environmental requirements of AD (Deublein et al 2008)

Parameter	**Hydrolysis/ Acidogenesis**	**Methanogenesis**
Temperature	25-35°C	Mesophilic: 30-40°C , Thermophilic: 50-60°C
pH Value	5.2-6.3	6.7-7.5
C:N ratio	10-45	20-30
Redox potential	+400 to -300 mV	Less than -250 mV
C:N:P:S ratio	500:15:5:3	600:15:5:3
Trace elements	No special requirements	Essential: Ni, Co, Mo, Se

In general MSW is deficient in both nitrogen and phosphorus with respect to microbial growth requirements in anaerobic digesters (Gray D, 2008). Nutrient requirements in AD can be supplemented by chemical addition or by introduction of organic materials rich in the needed nutrients. Higher gas production at the rate of 400 to 465 cum gas/MT of VS (volatile solid) with methane content about 55-60% is possible by blending primary sludge of sewage treatment plant with OFMSW in a ratio of 20% : 80% (sludge : OFMSW) (Michael K et al (Oct'81).

b) Product Output: In the bio gas produced from AD of OFMSW, methane content is about 55-56% of the total and there remain no significant differences for different proportion of feed materials (P. Zhang et al 2008). Methane is the most valuable component if the biogas is to be used as a fuel. If the methane concentration is increased to over 95 percent by removing the CO_2 and trace contaminants, the biogas can substitute for natural gas. The stabilized solid residue, from AD of OFMSW which is on an averages 40 - 60% by weight of the feedstock, can be used as soil conditioning material (Voegeli Y et al'07). One ton of organic waste in AD plant produces two to four times more methane in 3 weeks than a ton waste in a land fill would produce in 6 to 7 years (Hadi A et.al March 2012).

c) Issues and Challenges of AD: Production of bio gas from MSW through anaerobic digestion (AD) not only reduces the load on landfill site but also reduces the green house gas emission and conserve natural resources. Engineered landfills with gas collection always release substantial amounts of their overall GHG emissions to the atmosphere. AD has the highest potential for lowering GHG emissions related to waste treatment (Rollefson J May2005). European Union has already issued directives to their member countries to minimize landfills and to emphasis on AD, composting and WtE(karena M et al, 2012). In Canada AD is regarded as a major opportunity in helping to achieve the target of reduction of GHG emission. AD treatment of Canada's municipal waste is an attractive option which contribute a large Kyoto dividend through carbon credits (CDM). (Rollefson J May2005).

3.2.3 Incineration (WtE):

Incineration or Waste to Energy plants generate steam and or electricity from waste by burning mixed municipal waste into large furnaces.

Process Conditions: The ability of waste to sustain a combustion process without supplementary fuel depends on a number of physical and chemical parameters, of which the lower (inferior) calorific value (Hinf) is the most important. The minimum required lower calorific value for a controlled incineration also depends on the furnace design. The energy content of the water vapour accounts for the difference between a fuel's upper and the lower calorific values. The upper (superior) calorific value (Hsup) of a fuel, as per to DIN 51900, is the energy content released per unit weight through total combustion of the fuel. The temperature of the fuel before combustion and of the residues (including condensed water vapors) after combustion must be 25°C, and the air pressure 1 atmosphere. The combustion must result in complete oxidation of all carbon and sulphur to carbon- and sulphur dioxide respectively, whereas no oxidation of nitrogen must take place(*Rand T et al 2000*). The average lower calorific value of the waste must be at least 6 MJ/kg throughout all seasons. The annual average lower calorific value of fuel for combustion must not be less than 7 MJ/kg (*Rand T et al 2000*).

The three basic parameters for feasibility of combustion of waste, theoretically, without auxiliary fuel for incineration are i)Moisture of raw waste should be < 50 % , ii) Combustible fraction or ignition loss of dry sample should be > 25 % and Ash content or ignition residuals should be < 60%. To be economically feasible, the capacity of the individual incineration lines should be at least 240 t/d (10 t/h). The minimum capacity of each incineration line is 240 t/d (10 t/h) and the maximum is 720 t/d (30 t/h). There should be at least two incineration lines—so plants should be at least approximately 500 t/d capacity .The annual amount of waste for incineration should not be less than 50,000 metric tons per incineration line and the weekly variations in the waste supply to the plant should not exceed 20 percent. (*Rand T et al 2000*).

a) Product Output: n municipal waste to energy technology (WtE), the energy potential of waste depends on the mix of materials and their moisture content. The higher the calorific value of the waste the more energy can be extracted. In 100 tons of garbage, more than 60 to 80 tons, depending on the waste characteristics, can be burned as fuel to generate electricity at a power plant. . A typical Waste-to-Energy plant is able to produce 1.2MW – 1.5MW for every 100 tons of MSW (EPA, US, Resource Conservation and Recovery), depending on the scale of plant and MSW waste characteristics.

b) Issues and Challenges of Incineration or Mass Burn(WtE):

Environmental Issue: Incineration of MSW does not completely eliminate the waste volume, but significantly reduces the volume of waste to be land filled. The reductions are approximately 75 percent by weight and 90 percent by volume (*Rand T et al 2000*). There remain serious environmental issues associated with incinerating MSW to make electrical energy. Variety of pollutants is put into the atmosphere by burning the garbage in incinerators that power the generators. These pollutants are extremely acidic and have been reported to cause serious environmental damage by turning rain into acid rain. Concerns regarding the operation of incinerators include fine particulate, heavy metals, trace dioxin and acid gas emissions, even though these emissions are relatively low from modern incinerators. Other concerns include toxic fly ash and incinerator bottom ash (IBA) management. Residues produced from incineration include bottom ash (which falls to the bottom of the combustion chamber), fly ash (which exits the combustion chamber with the flue gas [hot combustion products], and residue (including fly ash) from the flue gas cleaning system.

Burning MSW produces nitrogen oxide and sulpher dioxide as well as trace amounts of toxic pollutants, such as mercury compounds and dioxins. The combined ash and air pollution control residue typically ranges from 20 % to 25% by weight of the incoming refuse processed. The average air emission rates from municipal solid waste-fired generation are: 1.67 MT/MWh of carbon dioxide, (it is estimated that the fossil fuel-derived portion of carbon dioxide emissions represent approximately one-half of the total carbon emissions), 5.49kg. /MWh of sulfur dioxide, and 3.04 kg. /MWh of nitrogen oxides.(EPA , US, Clean Energy). Although MSW power plants do emit carbon dioxide, the primary greenhouse gas, the biomass-derived portion is considered to be part of the Earth's natural carbon cycle.

Waste incineration in developing countries involves high investment costs with a large share may be of foreign currency and high operating and maintenance costs.Incineration of MSW entails a significant jump in technology and costs in comparison to composting and anaerobic digestion (*Rand T et al 2000*).Study indicates that waste-to-energy plants might not be economically sustainable if the MSW has a low energy recovery efficiency (less than 50% of the total heating value of fresh wastes). This is because the capital outlay for equipment installation and plant maintenance costs are so high that the energy benefits accruing may not suffice to offset this minimum balance (EPA, US, Resource Conservation and Recovery). The final recoverable energy output is strongly influenced by moisture content of urban solid waste.

Producing electricity from MSW may not be major advantage of waste-to-energy plants always. It actually may costs more to generate electricity at a waste-to-energy plant than it does at a coal, nuclear, or hydropower plant. But the major advantage of burning waste is that it reduces the amount of garbage we bury in landfills and does not consumes natural resources (EPA, US, Resource Conservation and Recovery). It saves fossil fuel, produces less amount of fly ash, avoids methane gas emission, saves land , reduces water pollution.

3.2.4 Thermal Gasification of MSW

There are a number of new and emerging technologies that are able to produce gas and or energy from waste and other fuels without direct combustion and among them i) Pyrolysis, ii) Pyrolysis, iii) Plasma gasification are most important technologies.

3.2.4.1 Pyrolysis

a) Process conditions : Pyrolysis is the thermo chemical degradation of organic waste at elevated temperature in an oxygen free environment, or in an environment in which the oxygen content is too low for combustion or gasification to take place. Pyrolysis is an endothermic reaction (unlike gasification and combustion, which are usually exothermic reactions) and requires an input of energy, which is typically applied indirectly through the walls of the reactor in which the waste material is placed for treatment. Pyrolysis typically occurs under pressure and at operating temperatures above 430°C.

b) Product output: The process generally produces a mixture of solid residues (char), oil and syn-gas or combustible gas(primarily methane, complex hydrocarbons, hydrogen and carbon monoxide). The ratios of each depends on the feedstock and the specific pyrolysis conditions (temperature, residence time, heating rate, pressure and degree of mixing) that are used. The producer gas which is generated can then be used in either boilers or cleaned up and used in combustion turbine/generators.

c) Environmental Issues: In this technology, air emissions may be easier to control than with mass burn technology because the gas produced by the pyrolysis or thermal gasification facility can be scrubbed to remove contaminants prior to combustion. However, scrubbing the producer gas at high temperature is currently under research and the technology has yet to be demonstrated on a large scale. In addition, the pyrolysis and gasifier streams may contain organic compounds of concern that are difficult to remove. (Source: The National Energy Education Project, USA).

3.2.4.2 Plasma Gasification Process (PGP)

Plasma gasification is a waste treatment technology that uses electrical energy and the high temperatures created by an electric arc gasifire to convert the organic waste into a fuel gas and the inorganic such as silica, soil, concrete, glass, gravel, etc. are vitrified into glass. Plasma plant is a machine that can get rid of almost any kind of waste and produce an excess of clean energy to be sold back to the grid (D Rafter, 2009). Plasma Gasification provides for a *sustainable* waste solution for all types of waste streams, including MSW, industrial waste, hazardous wastes which delivers tangible economic and environmental benefits . A new form of waste disposal – Plasma Gasification may provide municipalities with an efficient, quiet and clean way to dispose of their MSW. A plasma gasification plant ends the need for landfills.

a) Process Condition

Plasma arc gasification conversion System facilities can convert any type of waste ; municipal household waste , commercial or industrial waste, biomedical waste , construction debris etc in to green power. The plasma reactor does not discriminate between chemical and or physical characteristics of waste. Consequently, no sorting of waste is necessary and any type of waste, other than nuclear waste, can be processed. Plant size can be of any large size even each reactor can process 20 tons per hour (tph) or more . Because of the size and the negative pressure, the feed system can handle bundles of material up to 1 meter in size. This means that whole drums or bags of waste can be fed directly into the reactor making the system ideal for large scale production. Plasma arc breaks down waste primarily into elemental gas and solid waste (slag), in a device called a **plasma converter**. Relatively high voltage (650-volt), high current electricity is passed between two electrodes, spaced apart, where electrons are ripped from the air **making an electrical arc**, converting the gas into plasma. Inert gas such as pure nitrogen under pressure is passed through the arc into the sealed container of waste material, reaching temperatures as high as 13,900 °C (Credeur Mary Jane , June 2003) in the arc column. The temperature a few feet from the torch can be as high as 2,760–4,427 °C (The Recovered Energy System). As current continues to flow, it creates an intense energy field with plasma arcs, which are like lightning. At these temperatures the radiant energy about 16648^0C plasma arcs disintegrates most types of waste into basic elemental components by tearing apart the materials' molecular bonds in a gaseous form, and complex molecules are separated into individual atoms. All metals and other inorganics such as silica, soil, concrete, glass, gravel, etc. are become molten and vitrified into glass and flow out the botto m of the reactor. The reactor operates at a slightly negative pressure, meaning that the feed system is complemented by a gaseous removal system, and later a solid removal system. Syngas moves through a Gas Quality Control system and oxidized to CO_2 and H_2O in ceramic bed oxidizers and recovers sulfur, removes acid gases and segregates heavy metals found in the waste stream. The potential for air pollution is low due to the use of electrical heating in the absence of free oxygen.

a) Product Output: Plasma gasification produces syngas primarily composed of carbon monoxide (CO), hydrogen (2) and other gaseous constituents, and can be used for industrial purposes (as a substitute to natural gas). Non-gaseous, inorganic components in the gasified feedstock (i.e., the rocks, dirt and other impurities which do not gasify) separate and leave the bottom of the gasifier as a glass-like slag. Slag, which is environmentally clean and resembles glass, is a marketable aggregate material with a variety of uses in the construction and building industries. Syngas generated from plasma gasification has heat value of 320 Btu per cubic foot, or about 1/3 the Btu value of methane (natural gas). When combined with the nitrogen and water in the gas stream, the fuel gas has an overall Btu value of about 160 Btu per cubic foot. Plasma gasification does not have any negative impact on environment and will eventually be sold as green electricity. This clean syngas is used to fuel internal combustion engines that generate electricity.

c) Environmental Issues: The gas composition coming out of a plasma gasifier is lower in trace contaminants than with any kind of incinerator or other gasifier. Because the process starts with lower emissions out of the reactor it is able to achieve significantly lower stack emissions. It produces no emissions and no odors. There remains no tars or furans. It does not require much land because waste can be feed in big bundles. Best of all, the gas is created without generating any air emissions. There remains no ash to go back to a landfill.

3.2.4.3 Land Fill gas Extraction

Landfill of waste referred to as a biocell which involves sequential application of anaerobic degradation, aerobic decomposition and waste mining in a single waste cell. Biodegradation of waste in the biocell is enhanced through leachate re-circulation.

a) Process Conditions: Landfill gas extraction generally need to meet the criteria that 1 million tons of MSW has been deposited , has a depth of 50 feet or more, and is open or recently closed and the site should receive at least 25 inches of precipitation annually, to generate enough gas to support an LFG energy project [LFG Energy Project Development Handbook, Landfill Methane Outreach Program (LMOP), US EPA]. Because of the high degree of risk from improper waste disposal, landfill design and operation is highly regulated. There remains restrictive criteria regulating solid waste land filling with regard to groundwater quality protection, landfill gas controls, air pollution control, basic operating procedures, safety issues, flood plains, seismic and slope stability, disturbance of endangered species, surface water discharges, site closure and long-term care; and closure and long-term care financial assistance.Though, it is necessary to build landfill sites far enough away from populated areas for the smell not to be a problem, but it should be near enough for the transport of waste to be economical. Landfill area cannot be located near the air field.

b) Product Output: The main gases produced by a landfill site are methane and carbon dioxide. LFG contains roughly 50 percent methane and 50 percent carbon dioxide, with less than 1 percent non-methane organic compounds and trace amounts of inorganic compounds.[LFG Energy Project Development Handbook, Landfill Methane Outreach Program (LMOP, US Environmental Protection Agency)]. During its operational lifetime about 60 to 90 % of the methane created by a landfill can be captured, depending on system design and effectiveness. One million tons of MSW produces roughly 122310 cum per day of LFG and continues to produce LFG for as many as 20 to 30 years after being land filled. The LFG has heating value of about 500 British thermal units (Btu) per standard cubic foot of gas , which through various technologies, can generate approximately 0.78 megawatts (MW) of power or provide 9 million Btu per hour (MMBtu/hr) of thermal energy [LFG Energy Project Development Handbook, Landfill Methane Outreach Program (LMOP), US EPA]. Certainly these figures will vary depending on the composition of the waste and the temperature and rainfall in the area, gas collection system, compactness of the dump etc. In a landfill 73% of the LFG is generated within the first five years and 93% of the LFG is generated within the first ten years (E.A. McBean 2011) . The useful economic life of LFG project is about 15 fifteen years with a gradual reduction of gas production after about 10 years**.** (Landfill gas composition Handbook , EPA , US,).

c) Issues and Challenges :

Environmental Issues: Methane is a potent greenhouse (i.e. heat trapping) gas — over 20 times more potent than carbon dioxide, so is a key contributor to global climate change. Landfills are the second largest human-caused source of methane. Methane also has a short atmospheric life (10 to 14 years) (E.A. McBean 2011). The methane extracted from a landfill site should be used properly or burned off, otherwise if vented to atmosphere without burning (burning of LFG will produces carbon dioxide nothing else) it would add to global warming with a factor of 21 times more than the same quantity of carbon dioxide. land fill of one metric ton of MSW would produce approximately 62 cum methane via the anaerobic decomposition of the bio-degradable part of the waste. This amount of methane has more than twice the global warming potential than the 1 metric ton of CO2, which would have been produced by combustion. (Waste to Energy Research and Technology Council- Colombia).

Landfill gases may migrate from the landfill either above or below ground. Gases can move through the landfill surface to the ambient air. Once in the air, the landfill gases can be carried to the community with the wind. Odors from day-to-day landfill activities are indicative of gases moving above ground.

People may be exposed to landfill gases either at the landfill or in their communities. Gases may also move through the soil underground and enter homes or utility corridors on or adjacent to the landfill. Methane from landfills represents 12% of total global methane emissions (EPA 2006b). Landfills are responsible for almost half of the methane emissions attributed to the municipal waste sector in 2010 (IPCC 2007) .

If a landfill is covered after use, this gas will slowly seep through the earth covering and dissipate into the atmosphere, causing a long-term source of pollution and possible irritation for the local population. A large landfill with a high content of organic waste will probably produce methane for over fifty years after sealing. Studies revealed that cancer incidence and adverse reproductive outcomes (congenital malformations and low birth weight) are the main health effects possibly related to incinerators and landfills, respectively. (Francesco F, June 2011) . Until the landfill site has settled and the gas production has died down there is no way of reclaiming the land for building purposes, although the planting of trees and grass is possible in the interim.

4.0 Analysis:

4.1.0 Boundary Conditions of the Technologies:

Boundary conditions of the major waste processing technologies which are essentially required to be fulfilled for the sustainability of the system, as have been reviewed from the literature survey, are summarised in the following **'**Technology Summary Sheet' (Table No.- 2).

4.2.0 Sustainability of the Technologies

Sustainability of MSW processing and disposal technology depends upon multidimensional factors such as climatic conditions, environmental impacts, land criteria, economic & financial conditions, social and political condition. A technology becomes sustainable when it is technically suitable, financially viable, economically beneficial and socially accepted. Different factors and its elements which may influence the sustainability of municipal waste processing technology have been listed in the Table-3 **:**

Table 2:Technology Summary Sheet

Technology	**Input**		**Process Condition**	**Output**
	Nature of feed Stock	**Condition**		
Vermi Composting	Semi decomposed or fermented Bio-degradable matter. Worms: commonly redworms (Eiseniafoetida, Eiseniaandrei, and Lumbricusrubellus)	Should be free from toxic materials, sharp materials and CD.	Temp.: Optimum temp 12 to 25^{o}C, below 10^{o}C and above 30^{0}C is harmful. Humidity between 49 and 75% Excessive rain retards the processing	Compost manure or Soil conditioner
Windrow Composting	Bio-degradable waste	Should be free from toxic materials, and CD	Temp: Optimum 20^{o}C to 35^{0}C. Can work even at freezing temp and allowable moisture content between 30 and 90%, optimum 45 % to 50%, C : N ratio 20-30 : 1 and C: P ratio100 : 1	Compost manure or Soil conditioner
Anaerobic Digestion	Bio-degradable waste specially food waste , vegetable waste, etc.	Should be fed in small sizes. Presence of toxic material may reduce the digestion process	Temp : Range 25^{0}C to 60^{0}C. At lower temperature digestion process retards. In absence of oxygen.	Fuel gas and stabilised soil conditioner
Incineration (WtE)	Plant capacity should be at least 500 TPD , annual capacity > 50,000 MT . and the weekly variations should be <20 %. Individual incineration lines should be at least 240 t/d (10 t/h) and the minimum capacity of each incineration line should be 240 t/d (10 t/h) and the maximum 720 t/d (30 t/h). There should be at least two incineration lines.	lower calorific value of the waste should not be less than 6MJ/kg throughout all seasons. The annual average lower calorific value must not be less than 7 MJ/kg. Combustible waste should be without CD and PVC items	Moisture content of raw waste (W) < 50%, Ash content(ignition residuals) (A)< 60 %, and Combustible fraction (ignition loss of dry sample) C > 25 % must be maintained for combustion .	Flue gas and or electricity

Technology	Input: Nature of feed Stock	Input: Condition	Process Condition	Output
Pyrolysis	-do-	-do-	In absence of little amount of oxygen or without oxygen	Combustible gases ,liquids and solid residues or bio char.
RDF	Combustible waste without CD and PVC items.	calorific value must not be less than 7 MJ/kg.	-do-	Fuel cake
Plasma Gasification	Any type of waste	No restriction	In absence of oxygen	Rich syngas
Land fill Gas Extraction	All types waste (except inert materials) may be filled	Min. 1 million tons of MSW should be deposited	depth should be 50 feet or more, and it should be open or recently closed . Site should receive at least 25 inches of precipitation annually	Methane gas

Table 3:Factors which Influence the Sustainability of MSW Processing and Disposal Projects

Factors		Particulars/ Elements
Techno-logical	Waste	Waste Characteristics , quantity of waste, consistency of supply chain of raw materials,
	Climate	Rainfall , Temperature, Humidity, solar radiation and wind flow pattern, flood situation
	Land	Availability of land, Land restriction criterion,
Financial		Capital cost and O&M cost, availability of finance, cost of finance, tipping fee , price of auxiliary fuel or additive materials, CDM benefits etc.
Economical		Location of the plant, demand supply position of the product, Price of the product (output), Industrial scenario of the place, employment generation, savings of natural resources, GHG avoidance, availability of techno and equipment , availability of auxiliary fuel or feed materials, , saving of natural resources etc.
Environmental		Environmental rules and regulations, , Land use pattern, protection of ground water and water bodies, reduction of green house gas etc..
Social and Political		Culture and habits of the citizens, Govt. policies and procedures, political stability, acceptability of the society, availability of human resources,

5.0 Selection of Technology for Processing and Disposal of MSW:

Municipal solid waste management system cannot be made sustainable only with the technical end-of-pipe solutions but an integrated approach is necessary. Selection of technology for processing and disposal of MSW is to be made not only on the basis of quantity and composition of waste but the other factors (mentioned above) of the project location also have to be taken into consideration. For making a waste processing project sustainable at a place, the suitability of the technology in the prevailing local conditions should be ascertained first; then its environment friendliness, economic & financial viability, social acceptability and are to be checked .

Step-1: Short listing of Suitable Technology/Technologies

From the Literature review, expert opinion and practical field experience a 'Technical Parameter Indicative Chart' for different waste processing and disposal technologies has been developed in this study (Ref. Table- 4). This table indicates the degree of suitability of different solid waste processing technologies at various conditions.

Step-2: SWOT Analysis of the Technology

Once the technology /technologies is/are short listed then the positive and negative contribution of the various factors towards the sustainability of the project are to be evaluated. Depending upon the technology, some of the factors, which influence the sustainability of the project (referred in table No.3), may contribute positively and some may contribute adversely towards the sustainability of the project.Therefore, a SWOT analysis is required to be done for the selection of right technology.For the SWOT analysis, those factors may broadly be divided into two main groups; internal and external as stated below (Table No.- 5).

Table- 4: Technical Parameter Indicative Chart

Technical Parameter Indicative Chart

Indicators ➡ [Most Suitable (√)] • [Moderately Suitable (®)] • [Not Suitable (x)]

Particulars		**Internal and External Factors**	Vermi Composting	Windrow Composting	Anaerobic Digestion	Incineration	RDF	Pyrolysis	Plasma Gasification	Landfill Gas Extraction
			Technology and its Suitability Indicators							
Waste Characteristics		High Calorific Value >1200 Kcal/kg)	x	®	x	√	√	√	√	x
		High % of bio-degradable matter, >50%)	√	√	√	®	®	®	√	√
		Fixed Carbon < 25	√	√	√				√	√
		Total Inert > 25%	x	x	x	x	x	x	√	®
		C : N Ratio for composting 20-30 : 1	√	√	√			®	√	
		Mixed with all types of waste	x	®	x	®	®	®	√	®
Climate	**Temperature & Moisture**	Hot Climate >35^{0}C)	x	√	√	√	√	√	√	√
		Cold Climate < 10^0 C	x	®	®	√	√	√	√	®
		Moderate Climate 15^{0}C to 25^{0}C)	√	√	®	√	√	√	√	√
		High moisture content > 55%)	®	√	√	x	x	®	√	x
		Low moisture content (45-50%)	®	√	√	√	√	√	√	√
	Rainfall	High Rainfall area	x	x	√	x	x	®	√	x
		Low Rainfall area	®	√	√	√	√	√	√	√
		Moderate rainfall area	√	√	√	√	√	√	√	√
		High Solar radiation area	x	√	√	√	√	√	√	√
Land	**Location**	High environmental regulation	®	x	√	x	x	®	√	x
		Near residential area	X	X	√	X	X	X	√	X
		Near water body	®	®	√	X	X	X	√	X
		Near airport	®	X	√	X	X	X	√	X
		Near monument	®	®	√	X	X	®	√	X
	Area	Sufficient land area Available	√	√	√	√	√	√	√	√
		Limited land area Available	x	x	√	√	√	√	√	x
		High Land Location Restrictions	x	x	√	x	√	√	√	x
	Plant Size	Up to 25 TPD	√	x	√	x	x	x	x	x
		25 to 50 TPD	®	x	√	x	x	x	x	x
		50 to 100 TPD	x	x	√	x	x	x	x	x
		100 to 500 TPD	x	®	√	√	®	®	√	x
		Above 500 TPD	x	√	√	√	√	√	√	√
Economic Conditions		High Capital Cost	x	x	x	x	x	x	x	x
		Low Capital Cost	x	®	®	®	®	®	x	x
		Resource Conservation	√	√	√	√	√	√	√	√
		Carbon Credit advantages	√	√	√	®	®	®	√	®

The above table will help to identify the technologies which are suitable for the local conditions.

The effect of the internal factors can be adjusted or mitigatedbut the effect of the external factors are rigid and may be a yard stick for the selection of right technology. So, the degree to which the parameters of the short listed technologies match with the external factors is very important.

In the SWOT analysis, the degree to which the factors match with the project requirements may be termed as 'SWOT Ranking'. The sustainability of any waste processing technology will largely depend on the 'SWOT Ranking'. The SWOT Ranking may be placed in the scale range of (+)10 to (–)10 as follows:

Table 5: Internal and External Factors

Internal Factors **strength or weakness(*)**	**External Factors** **opportunity or threats(*)**
Quantity and characteristics of MSW, availability of recycling facilities, risk factor of getting right kind of MSW, capital cost and O&M cost, availability of land area, location of Land, proximity to other urban centers, scope for public private participation (PPP), scope for backward and forward integration, availability of indigenous technology, scope for natural resources conservation, environmental issues.	climatic condition, land restriction criteria, cost of capital, availability of raw materials for auxiliary fuel/additives, market condition, socio economic condition, national and international regulations, local constraints, political situation,

[Note: (*)depending upon their effect on the project's objectives

SWOT Ranking Scale

		SWOT Ranking		Remarks
		SWOT	Rank	
SWOT	Strength (S) & Opportunity (O)	Extremely favourable	(+)10 to (+) 6	Ranks are to be assigned based on actual situation and practical field experience. Help of QFD (Quality Function Deployment) methods may also be taken.
		Moderately favourable	(+)5 to (+)1	
	Weakness (W) & Threat (T)	Moderately unfavourable	(-)1to(-)5	
		Extremely unfavourable	(-)6 to (-)10	

(-)10 ←→ **(-6)**	**(-)5** ←→ **(-1)**	**(+1)** ←→ **(+5)**	**(+6)** ←→ **(+10)**
Extremely unfavourable (T)	Moderately unfavourable (W)	Moderately favourable (O)	Extremely favourable (S)

This SWOT analysis report (alternatively SWOT matrix) will identify the internal and external factors which are favourable and which are unfavourable to achieve the objective of the project.

Step-3: Determination of Strategic Fit

After the SWOT analysis report is completed the SWOT list will become a series of recommendations for developing a strategic plan. Based on the 'SWOT Ranking' of the SWOT report a brain storming season allowing the participants and stack holder to creatively brainstorm, identify obstacles and strategize possibly solutions to those limitations, which may be termed as 'Strategic Fits'. This eventually will identify the most suitable technology or a combination of technologies for the municipal solid waste processing and disposal project of a city.The evaluated SWOT involved in the project will help to develop a comprehensive structured planning process for the sustainability of the SWM system.

6.0 Result and Discussion:

Identification of SWOTs in SWM processing and disposal project is important because they help in planning to achieve the objective. First, the decision makers should consider whether the objective is attainable, given the SWOTs. If the objective is not attainable a modified or different objective must be selected and the process is to be repeated. Users of SWOT analysis need to ask and answer questions that generate meaningful information for each strategic fits to make the analysis useful and find their competitive advantage. The framework of the selection of technology for the processing and disposal of MSW is presented below (Figure 2)

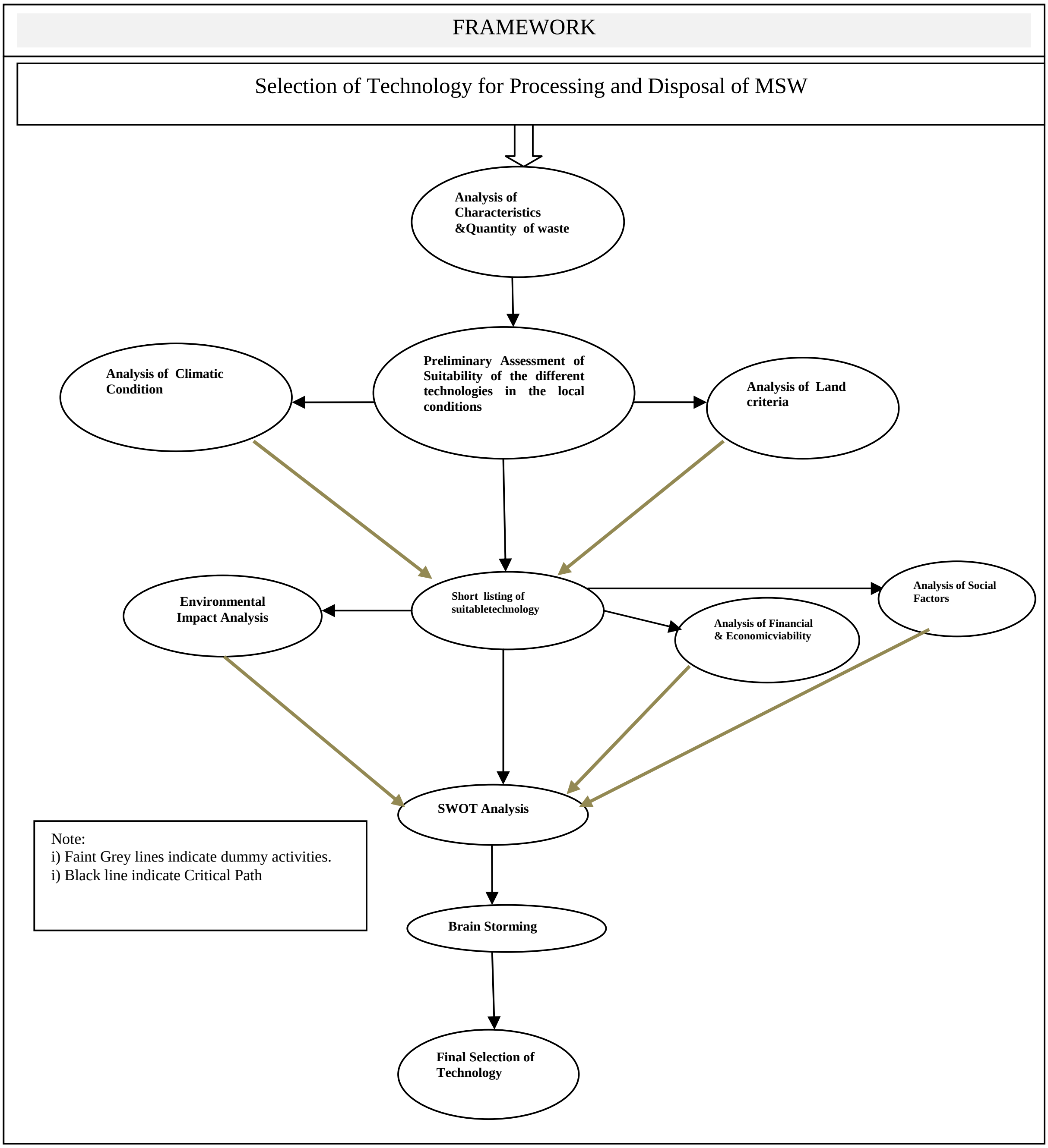


Fig. 2: Framework of SWOT analysis.

Considering the above, a 'Model SWOT Analysis Report' sheet has been developed in this study which is given in**Annexure- I** of this paper. A model questionnaire for obtaining the required information for the SWOT analysis has also been developed in this study(Ref. Annexure-II).

7.0 Conclusion:

The use of SWOT analysis for selection of technology for processing and disposal of MSW will help to mitigate the uncertainties and minimise the business/project risk and will also help to i) identify the raw material feed mix, ii) establish a raw material supply chain, iii) identify the product mix and product market, iv) business model & business risk and v) social barrier etc which will go long way for sustainability of the MSW management system.

Management information that will come forward from SWOT analysis may be divided into two main categories:

		Attributes
Internal factors	Strengths (S)	Characteristics of the place that give advantage(s) to the technology of the project.
	Weakness (W)	Characteristics of the place which is/are advantage(s) for the technology of the project.
External factors	Opportunities (O)	elements that the project could exploit to its advantage
	Threats (T)	elements in the environment that could cause trouble for the project.

Annexure - I

Model SWOT Analysis Report Sheet for MSW Processing and Disposal Project

Project Title:	XYZ....	
Technology:	Abc..	
Name of City:	PQR...	Date: xx.xx.xxxx

PART- I Internal Factors

	Particulars	**Project Requirements** (put the values from the 'Sustainable Parameter Indicative Chart' wherever applicable)		**Assessment Report** (put the values from the analyzed data of questionnaire wherever applicable) (please write **NA** wherever the information is not required)	**Identified SWOT Rank**
	a)Waste Parameters				
Waste Criteria	Total Quantity of specified waste (MT)	Min. Possible Capacity	…TPD	………MT daily	
		Maximum Possible capacity	…TPD		
	Composition of waste	Min. % of degradable waste	…..%	……..%	
		C:N	………	………	
		Min. calorific value required	....Kcal	………..Kcal	
		Optimum moisture content	…..%	…………..%	
	Anticipated guarantee of availability of right kind of waste	Minimum % Required		Please explain	
	Possibility of seasonal Variation of waste i)Characteristics, ii)Quantity	i)Tolerance limit in %		Anticipated chances of variation……..%	
		ii) Tolerance limit in %		Anticipated chances of variation……..%	
	Maximum plant size possible			…....TPD	
	Overall Ranking on Waste Criteria				
Land Condition	b) Land Criteria				
	Land area required (sq.m)	Min. requirement	…...m^2	Available land……...m^2	
		Desirable	…...m^2		
		Comfortable	…...m^2		
	Distance of land from waste source	Matters greatly/does not matter greatly(Please √ and explain)			
	Cost of land	Matters greatly/Does not matter greatly(Please √ and explain)			
	Land Location Restrictions	Water body/ Airport/Human habitation/Religiousplace/ Monument/Not applicable *(Please √ whichever is applicable and explain)*			
	Maximum plant size possible	→			
	Possibility of availability of the land in future *(Please √ whichever is applicable)*	Essentially required/ Not required/better if available*(Please √ whichever is applicable)*		Available or Not (Please √ and explain)	
	Land use pattern of that area			Affects/does not affects	
	Overall Ranking on land criteria fulfilment				

	Particulars	**Project Requirements** (put the values from the 'Sustainable Parameter Indicative Chart' wherever applicable)		**Assessment Report** (put the values from the analyzed data of questionnaire wherever applicable) (please write **NA** wherever the information is not required)	Identified SWOT Rank
Economic Condition	Availability of recycling facilities				
	Clubbing with other Urban areas	Possible / not possible (Please √) .		Please explain	
	Capital cost			High/Low(*Please* √)	
	O& M Cost			High/Low*(Please* √)	
	Nearby industry to consume product(s)	Possible / not possible (Please √)		Please explain	
	Scope for alliance with other business house	Possible / not possible (Please √)		Please explain	
	Scope for backward or forward integration	Possible/Not possible(Please √)		Please explain	
	Flexibility of processing right kind of product mix	Yes/No (Please √)		if yes , Pl. specify	
	Overall Ranking on Economic Condition				
	Part-II External Factors Moderately favourable opportunity(O) or Extremely unfavourable Threat (T)				
Climatic Condition		Project Perspective		Assessment Report	
	Particulars	Attributes	Project Perspectives	Please put the details information	Identified SWOT Rank
	Temperature (^{0}C)	Optimum	………^{0}C	Max……^{0}C ; Min. ……^{0}C	
		Acceptable	………^{0}C		
		Unsuitable	………^{0}C		
	Rainfall	Suitable		Max.……mm; Min………….mm	
		Unsuitable			
	Humidity	Suitable	. ……….%	Max……….%; Min………..%	
		Unsuitable	. ……….%		
	Solar condition *(Please √ whichever is applicable)*	High /Low solar Zone *(Please √)*	Matters Favourably/ unfavourably/Does not matter*(Please √)*	(Please explain)	
	wind condition *(Please √ whichever is applicable)*	High /Low wind velocity Zone*(Please √)*	Matters Favourably/ unfavourably/Does not matter*(Please √)*	(Please explain)	
	Overall Ranking on climatic conditions				
Market Conditions	Distance of market/ consumer	Matters / Does not matter (Please √) If yes →		favourable/ unfavourable (Please√ and explain)	
	Transportation facilities for product	Matters / Does not matter (Please √). If yes →		favourable/ unfavourable (Please √ and explain)	
	Packaging requirement	Matters / Does not matter (Please √). If yes →		(Please explain)	
	Scope for Placement of the product in the nick market	Matters / Does not matter (Please √). If yes →		High/ low (Please √ and explain)	
	Overall Ranking on market conditions				
EconomicCondition	f) Economic Factors				
	Minimum supply of product need to be guaranteed	Applicable/ Not Applicable (Please √), If yes explain		if yes , Pl. explain	
	Scope for Public Private Participation (PPP)	Matters / Does not matter(Please √) If yes explain		if yes , Pl. explain	
	Scope for saving of natural resources from the project	Yes/No *(Please √)*		if yes , Pl. specify	
	Benefit of carbon Credits	Possible/Not possible (Please √), if possible explain		if possible explain	
	Saving of land area	Yes/ No (Please √) if yes explain		if yes , Pl. explain	
	Overall comment on economic scenario				
	g) Financial Factors				

	Particulars	Project Requirements (put the values from the 'Sustainable Parameter Indicative Chart' wherever applicable)		Assessment Report (put the values from the analyzed data of questionnaire wherever applicable) (please write **NA** wherever the information is not required)	Identified SWOT Rank
Financial Conditions	Availability of fund	(Please explain)			
	Availability of financial subsidy/ concession from Govt.	(Please explain)			
	Possible rate of tipping fee (INR/MT)	(Please explain)			
	Cost of fund	(Please explain)			
	Pay Back Period	(Please calculate and put the figure)			
	NPV	(Please calculate and put the figure)			
	ROI	(Please calculate and put the figure)			
	Overall comment on financial parameters				
Social Conditions	h) Social Factors				
	Anticipation of the acceptability of the product by the community	(Please explain)			
	Employment generation	High/Moderate/Low(Please √),	(Please explain)		
	Overall Rating on social factors				
	i) Local conditions				
Local conditions	Scope for addition of other locally available value additive Ingredients with the waste if any	Yes/No (Please √ and Explain),		Pl. specify if yes	
	Scope for any alternative auxiliary fuel(s) (for power generation)	Yes/No (Please √ and Explain),		Pl. specify if yes	
	Grid Connectivity Position (for Power Generation)	Applicable/ Not Applicable (Please √ and Explain if yes),		(Please explain)	
	Present Tariff of electricity of that area (for Power Generation)	Applicable/ Not Applicable (Please √),		(Please explain)	
	Availability of manpower	(Please explain)			
	Local constraints if any	(Please explain)			
	Overall rating on Local Conditions				
Environmental Conditions/ Regulations	j) Environmental				
	Susceptible to air pollution	Yes/No (Please √)	if yes , Pl. specify	Yes/No (Please √)	
	Susceptible to water pollution	Yes/No (Please √)	if yes , Pl. specify	Yes/No (Please √)	
	Susceptible to Noise pollution	Yes/No (Please √)	if yes , Pl. specify	Yes/No (Please √)	
	GHG emission reduction from the project	Yes/No (Please √)	if yes , Pl. specify		
	Occupational Health hazards	Yes/No (Please √)	if yes , Pl. specify		
	Impact on community health	Yes/No (Please √)	if yes , Pl. specify		
	odour problem	Yes/No (Please √)	if yes , Pl. specify		
	Special National and international regulations for that technology	Yes/No (Please √)	if yes , Pl. specify		
	Special environmental restriction in that region	→	→		
	Overall comment on environmental compliance				

Annexure-II

Model Questionnaire for Data Collection for SWOT Analysis:

Classified Data for SWOT analysis of MSW Processing Project						
Name of Town: ……………………………………,						
Particulars			**Average Characteristics**			
a. Waste		**Quantity (TPD)**	**Av. Calorific Value**	**% of bio-degradable matter**	**% of inert**	**Anticipated Seasonal Variation**
I) Waste quantity from Various sources						
Domestic waste	:					
Offices/ Institutions (schools , colleges, universities etc.)	:					
commercial complex/ shopping Mall etc	:					
Parks and gardens	:					
airports, Railway stations/ bus terminus	:					
Daily market	:					
Wholesale vegetable, market fruit, flower market, fish market						
Kitchen and food waste from restaurant/hostel hostel/canteen	:					
Waste from slaughter house/ stable/farm house etc	:					
Any other (pl specify………………….)	:					
Any other (pl specify………………..)	:					
Specific waste Criteria if any(pl specify…….)	:					
II) Average **Waste Quality of the city**						
Calorific Value of waste	:					
% of bio-degradable matter in MSW	:					
Seasonal Variation of the Waste	:					
% of inert in the waste	:					
Possible variation anticipated (day basis)	:					
Brief description on waste Generation pattern and sources :						
b. Land						
Land area available	:					
Depth of ground water table						
Distance from air port (if any)						
Distance from historical monument (if any)						
Distance from water body(if any)						
Distance from monument(if any)						
Distance from nearby locality						
Distance of available land from Waste source						
Brief description on land location for that project :						
c. Climatic condition of that area	:					
Rainfall						
Maximum and Minimum Temperature (Summer and winter)	:					
Humidity (Maximum and Minimum)	:					
Solar condition	:					
Wind flow condition						
Brief description on Climatic condition of that area :						
d. Economic						
Possible Market/Prospective Buyers	:					
Prevailing market price of the product	:					

Present Tariff of electricity(for generation of power)	:	
Potential for Placement of the product in the nick market	:	
Distance of nearby locality (for using gas as cooking fuel)		
Any locally available cheap additives /Auxiliary Fuel etc	:	
Sources of auxiliary Fuel(s)if any (for generation of power)	:	
Cost of auxiliary fuel(s) / additive	:	
Grid Connectivity Position(for generation of power)	:	
Quality Assurance capability	:	
Related industries in that area suitable for business alliance	:	

Brief description on economic condition of that area :		
a. Financial		
Cost of fund		
Cost of land		
Fund Availability		
Possible Tipping fee		
Availability of Govt. subsidy		
b. Social		
Awareness	:	
Acceptability of the project in the market as a whole	:	
Availability of labour	:	
Availability of skilled workers	:	
Community participation	:	
Political stability		
Brief description on social condition of that area :		
c. Environmental		
Average air pollution level of that area		
Special environmental regulations of that region if any		
Land use map of that area		
Brief description on social conditions of that area :		

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