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Waste to Energy Technologies for Sustainable MSW Management - An Overview

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Abstract - Rapid population growth, Urbanization, Industrial growth is increasing the generation of municipal solid waste (MSW) day by day in developing countries like India. The management of MSW is very severe problem and biggest challenge not only because of environmental and aesthetic concerns but also the potential threat to public health, resulting improper and non-scientific handling of municipal waste due to enormous quantities generated every day. In India the average MSW generation is 450 gm/per capita/day. Inappropriate disposal of waste creates various health effects and pollution in the environment. The preferred Integrated Solid Waste Management System (ISWMS) strategies within the hierarchy includes at-Source Reduction and Reuse, Recycling, Composting, Waste to Energy (WtE) & Landfills. Among these WtE is safe, economical, eco-friendly, minimizes the amount of disposal of MSW, and also accepted socially.

Recovering energy before final disposal of MSW can be achieved through production of heat, electricity, or fuel and WtE technologies viz. Incineration, Pyrolysis (syngas), Gasification, Refuse derived fuel(RDF), fuel in cement kilns/Iron/steel industries, biodiesel, etc. through thermal, biological and chemical processes. Segregation of wastes at source is highly important to make the system more efficient for energy recovery and involvement of all investors and Govt. also in effectively managing MSW to fulfil the objective of zero waste going to landfills. This paper deliberates on how WtE technology is feasible, financially reasonable, environmentally benefit able, analysis of energy generation, revenue from waste, status of WtE plants, issues and challenges of handling waste, separation methods, pollution control, public awareness and selection of suitable disposal technologies ensuring successful integrated MSW management and also consider the future aspects of WtE in India along with a few recommendations for the course of action and for developing better, effective WtE technologies as part of 'Swachh Bharat Mission'.

Keywords— Waste to Energy; Integrated Municipal Solid Waste management; Technologies; Standards; Pollution

I. INTRODUCTION

Rapid urbanization, urban growth and economic development have not only changed the physical size of the cities but is also exerting significant additional pressure on the infrastructural services across all cities. Over the last two decades rapid urbanization, change in life styles, steep increasing population, the management of MSW in the country has emerged as a severe problem not only because of the environmental and aesthetic concerns but also because of the huge quantities generated every day. The MSW, is a heterogeneous mixture of paper, plastic, cloth, metal, glass, organic matter, construction and demolition debris, dust, etc., generated from households, commercial establishments, markets and road cleaning activities. According to the Central Pollution Control Board (CPCB) 1,42,566 TPD (tons per day) of MSW was generated daily which is around 531.53 lakh tons per annum in India during the year 2017. Of the total waste generated, approximately 1,17,644 TPD (80.78%) of MSW was collected and only 33,660 TPD (27.86%) was processed or treated [7]. CPCB conducted study in 60 major cities of India and estimated that around 4059 TPD of plastic waste is generated from these cities. Based on this it is expected that around 26,000 TPD of plastic waste is generated in India. Around 3,40,000 cubic metres of landfill space every day, if the rate of present generation of waste continues to be dumped on landfill without any treatment. Planning Commission Report (2014) reveals that Considering the projected waste generation of 165 million tonnes by 2031, the requirement of land for setting up landfill for 20 years (considering 10m high waste pile) could be as high as 66,000 hectares of precious land, which the country cannot afford to waste. [11]

The quantity of generated MSW is higher than the collected waste, results uncollected waste in streets, common places and road side drains and collected waste is generally dumped on the peripheries of towns or cities and has made serious public health problems and causes of surface and groundwater contamination, air and water pollution. Waste plastic has one of the main challenges in MSW, leading to a severe problem of obstructing of waterways and drains, debasement the landscape and killing of cows. Thus, there is an urgent need to improve planning of collection, segregation and disposal of wastes so that solid waste management process works significantly to create environmental friendly environment.

Therefore, the usage of 4R's (Reduce, Reuse, Recycle and recover) should be done for environmental sustainability. The MSW management sector is governed by the MSW Management Rules,2016, Government of India. The typical MSW management value chain includes various stages i.e. primary and secondary collection, transportation, intermediary storage in a transfer station, process/treatment like WtE and disposal in an environmentally sound and appropriate manner. This paper deliberates smart waste management system of WtE technology in detail.

1.1 Municipal solid waste: Generation, composition and potential

Waste is an inevitable product of society, and one of the greatest challenges for future generations is to understand how to manage large quantities of waste in a sustainable way 'waste' is any unwanted material or substance that results from human activity or process and material that is not productive and has no value for the generator for further use for the purpose production, transformation or consumption. Any waste generated in solid form can be classified as solid waste. MSW contains organic as well as inorganic matter. MSW generation in India is 450 gm/per capita/day.

The MSW generation rate in the country is 200-300 gm/capita for small towns, 300-400 gm/capita for medium cities and 400-600 gm/capita for large cities and facing a huge challenge to properly manage waste. Faced with huge volumes and heavy expenditure for management, efforts should be made to reduce waste volumes and generate earnings from treatment thereof. The composition of municipal solid waste varies greatly from place to place and from time to time. It predominately includes food waste, household waste, market waste, packaging materials and products which are no longer useful. The sources can be residential, commercial, institutional and industrial. In the definition of municipal waste, the industrial waste, agricultural waste, medical waste, radioactive waste or sewage sludge is not included. Improper waste management is one of the main causes of environmental pollution and contributes to air, land and water contamination. Table 1 showing the type and sources of MSW in India

Table 1 *–Type and sources of MSW*

Source / type	Composition	
Municipal solid waste	Housing waste	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, , household hazardous wastes, e-wastes, special wastes (e.g. bulky items, consumer electronics, white goods, batteries, oil, tyres),etc
	Industrial waste	Housekeeping wastes, , wood, steel, concrete, bricks, ashes, hazardous wastes, packaging, food wastes
	Commercial & institutional	Paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes, hazardous wastes, e-wastes.
	Building Construction & destruction	Bricks, Stone, Tiles, Earth, Steel, Stone ware pipes, Pipes, Electrical fittings, wires, switches, Concrete, hazardous waste ,wood materials,etc.
	Municipal services	Street sweepings, landscape & tree trimmings, sludge, wastes from recreational areas.
Process waste	Scrap materials, off-specification products, slag, tailings, top soil, waste rock, process water & chemicals.	
Medical waste	Infectious wastes (bandages, gloves, cultures, swabs, blood & bodily fluids), radioactive wastes, pharmaceutical wastes, hazardous wastes (sharps, instruments, chemicals),etc.	
Farming waste	Rice husks, Shells of coconut , veterinary medicine , pesticides , feed effluent, plastic, scrap equipment,etc	

1.2 Objectives and functional elements of MSW management

1. To explore various Waste to Energy technologies available in India and suitability analysis
2. To reduce the quantity of solid waste disposed off on land by recovery of material and energy from solid waste.
3. Method to ensure effective waste collection and safe segregation of waste at the source place
4. To prove that WtE concept is economically and environmentally sustainable
5. To reduce and eliminate adverse impacts of waste material on human health and the environment to support economic development and superior quality of life
6. The role of Govt./ Urban Local Bodies(ULBs)/ Municipal Corporation (MC)/Swachh Bharat Mission on WtE technology for more effective SWM system in India.
7. Identified various advantages and constraints of WtE technologies
8. Methods for minimise the pollution level during the process and enhance the efficiency of the WtE process.
9. Cost analysis of WtE plant and system, Selection of suitable WtE Technology

The six functional elements are Waste generation, Waste handling and sorting, storage and processing at the source, Collection, Sorting processing and transformation, Waste processing and recovery, Safe disposal.

II. STATISTICS ON WASTE GENERATION AND WASTE CHARACTERIZATION DATA

Generating MSW are based on quality of living, life style, type of commercial activity, habits of eating, place of city/region and season. Table 2 provides data on MSW generation in different states. Figure 1 provides sources and figure 2 provides composition of MSW in India.

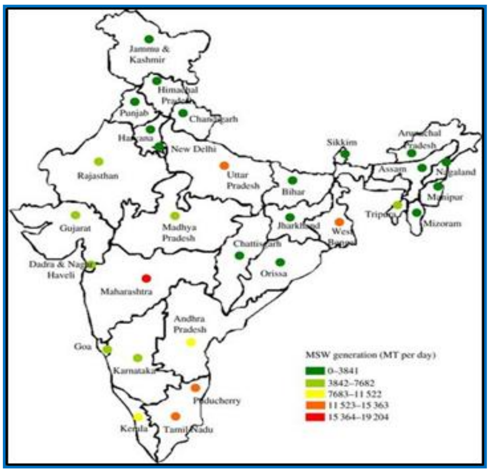

Fig .1 *State-level statistics of MSW generation in India. Source:CPCB GoI*

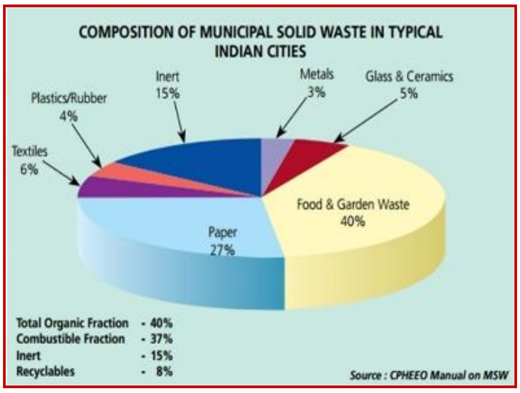

Fig. 2 *Composition of MSW*

Table.2*-State-wise waste & treatment report (Source CPCB Report)*

S.No.	States	Quantity Generated (TPD)	Collected (TPD)	Collected %	Treated (TPD)	Treated %
1	Andaman & Nicobar	70.00	70.00	100.00	5.00	7.00
2	Andhra Pradesh & Telangana	11500.00	10656.00	93.00	9418.00	82.00
3	Arunachal Pradesh	110.00	82.00	82.00	74.00	74.00
4	Assam	650.00	350.00	54.00	100.00	15.00
5	Bihar	1670.00	0.00	0.00	0.00	0.00
6	Chandigarh	340.00	330.00	97.00	250.00	74.00
7	Chhattisgarh	1896.00	1704.00	90.00	168.00	9.00
8	Daman Diu, & Dadra	85.00	85.00	85.00	0.00	0.00
9	Delhi	8390.00	7000.00	83.00	4150.00	49.00
10	Goa	183.00	182.00	99.00	182.00	99.00
11	Gujarat	9227.00	9227.00	100.00	1354.00	15.00
12	Haryana	3490.00	3440.00	99.00	570.00	16.00
13	Himachal Pradesh	300.00	240.00	80.00	150.00	50.00
14	Jammu & Kashmir	1792.00	1322.00	74.00	320.00	18.00
15	Jharkhand	3570.00	3570.00	100.00	65.00	2.00
16	Karnataka	8784.00	7602.00	87.00	2000.00	23.00
17	Kerala	1576.00	776.00	49.00	470.00	30.00
18	Lakshadweep	21.00	-	0.00	-	0.00
19	Madhya Pradesh	5079.00	4298.00	85.00	802.00	16.00
20	Maharashtra	26820.00	14900.00	56.00	4700.00	18.00
21	Manipur	176.00	125.00	71.00	-	0.00
22	Meghalaya	268.00	199.00	74.00	98.00	37.00
23	Mizoram	552.00	276.00	50.00	0.00	0.00
24	Nagaland	270.00	186.00	69.00	18.00	7.00
25	Orissa	2460.00	2107.00	86.00	30.00	1.00
26	Puducherry	495.00	495.00	100.00	0.00	0.00
27	Punjab	3900.00	3853.00	99.00	32.00	1.00
28	Rajasthan	5037.00	2491.00	49.00	490.00	10.00
29	Sikkim	49.00	49.00	100.00	0.30	1.00
30	Tamil Nadu	14532.00	14234.00	98.00	1607.00	11.00
31	Tripura	407.00	407.00	100.00	0.00	0.00
32	Uttar Pradesh	19180.00	19180.00	100.00	5197.00	27.00
33	Uttarakhand	1013.00	1013.00	100.00	0.00	0.00
34	West Bengal	8674.00	7196.00	83.00	1415.00	16.00
	Total (TPD)	**1,42,566.00**	**1,17,645.00**		***33,660.30***	

According to Report of Task Force on Waste to Energy, In urban areas projected 62 Million tonnes of MSW waste is generated annually by 377 Million people in India, of which around 75 to 85 % is disposed of extensively at dump yards leading to problems of health and environmental degradation. The Central Public Health and Environmental Engineering Organization (CPHEEO) under Ministry of Housing and Urban Affairs has developed the Municipal Solid Waste Management Manual 2016, which provides detailed guidance to urban local bodies on the planning, design, implementation and monitoring of comprehensive municipal solid waste management systems.

From the above table it is observed that the waste that is treated is abysmally low. As per CPCB study conducted by National Environmental Engineering Research Institute (NEERI), waste that is generated in the country is a mixed waste comprising a large amount of inert material and a very high moisture level unlike in other countries. High level of moisture and inerts in the waste make it difficult to derive power from it. It is found that there is no proper public system of primary collection from the source of waste generation and municipal sanitation workers collect waste primarily through street sweeping, etc. Also, there is no practice of sorting of waste at source in a scientific way. Citizens should be encouraged to keep segregated containers for wet, dry and hazardous waste and stop littering on the streets. Segregation of waste should be made mandatory and if need be a penalty may be imposed for non-compliance. The categorization of MSW is based on their types and source of generation (i.e. residential, commercial, industrial, etc.).

2.1 Physical & Chemical characteristics of MSW in Indian Cities

Figure 3 and Table 3 shows the physical and chemical characteristics of municipal solid waste in Indian cities. MSW are found such as, street sweeping waste, industrial waste, construction and demolition waste, food waste, rubbish, commercial waste, institutional waste and sanitation waste. MSW contains compostable organic matter, recyclables, toxic substances, and soiled waste and part of these are combustible and some waste are non-combustible materials.

The key challenges of MSW management includes primary collection at the doorstep, Unwillingness in public to take possession, Unavailability of satisfactory funds, Deficiency of access to proper treatment technology; and Unscientific method of disposal of MSW at dump sites. The MSW guidelines cover all the aspects from the beginning stage of waste collection to safe disposal of waste.

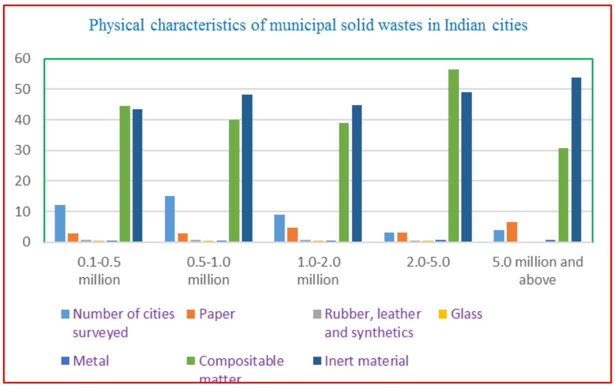

Fig. 3 Physical characteristics of MSW in Indian cities

Table 3 *Chemical characteristics of MSW in Indian cities*

Population range	Number of cities surveyed	Moisture %	Organic Matter %	Nitrogen as total nitrogen %	Phosphorous as P_2O_5 %	Potassium as K_2O %	C/N ratio	Calorific Value in kcal/kg
0.1-0.5 million	12	25.81	37.09	0.71	0.63	0.83	30.94	1009.89
0.5-1.0 million	15	19.52	25.14	0.66	0.56	0.69	21.13	900.61
1.0-2.0 million	9	26.98	26.89	0.64	0.82	0.72	23.68	980.05
2.0-5.0 million	3	21.03	25.6	0.56	0.69	0.78	22.45	907.18
5.0 million and above	4	38.72	39.07	0.56	0.52	0.52	30.11	800.7

All values, except moisture are on dry weight basis
Source: Manual on Municipal Solid Waste Management, Ministry of Urban Development,GoI
Calorific value on dry weight basis.

2.2 Integrated municipal solid waste management (IMSWM) system

Waste management is the collection, transport, processing, recycling or disposing, managing and watching of waste materials process. IMSWM system refers to generation of waste, classification of waste, transfer from place to place, sorting the waste, proper method of treatment, recovery and disposal of waste materials in accordance with the MSW (M&H) Rules, 2000. This model is based on 4Rs such as Reduce, Reuse, Recycle and Resource. This focuses on the three basic principles are *Equity*, *Effectiveness and Efficiency*. Efficient management of all waste is done by increasing the benefits, reducing the costs and adjusting the use of resources on sustainable basis. The three basic concept models of ISWM are Lifespan, Generation of waste and management of waste. The hierarchy of IMSWM are 1) *Reduction of waste at source and reuse, Recycling, Waste to Compost and Waste-to-Energy (Generation* of heat, electricity or energy from the waste using Incineration, gasification, Pyrolysis, Bio-methanation and Refuse Derived Fuel) and good system for *Waste Disposal. This system* can help avoid emissions of greenhouse gases, reduces contaminants, save energy, preserves resources, create job opportunity and encourage the progress of green technologies like '*Waste to Wealth & Energy'*

2.3 The waste management hierarchy

The waste management hierarchy, as shown in Figure 4 & 5 describes the preferred course of action for managing waste. Different versions of the hierarchy are adopted, but they all follow a step-wise process for waste where prevention, minimisation, and reuse (& recycling) of waste products are prioritised.

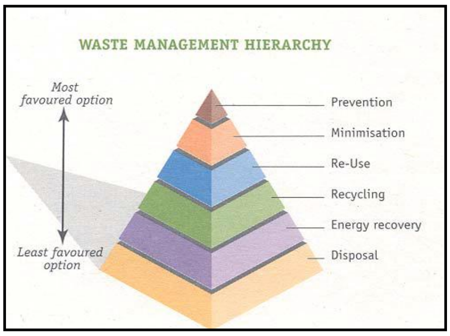

Fig. 4 Waste management hierarchy

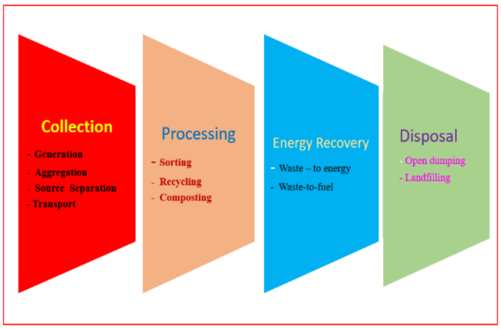

Fig. 5 Sustainable MSW management chain and flow

2.4 Management value chain for MSW

Sustainable waste management systems can then be developed based on the hierarchy, from waste collection to final disposal. However, in some contexts the waste hierarchy is not necessarily the most sustainable route for waste management, but adopting alternative process steps that use life cycle thinking which do not follow the hierarchy, can be a more sustainable solution. Figure 5 is an example of a waste management value chain that follows the waste management hierarchy.

III. WASTE TO ENERGY- 'SWACHCHATA SE SWACHH URJA'

Waste to Energy (WtE) is a relatively new technology where electricity or heat is generated through preliminary treatment of MSW. A WtE system uses waste as renewable fuel and generates energy. Waste to Energy technology will reduce the solid waste volume by around 85 to 90% and the remainder of 10% to 15% can be carefully disposed off in landfills. Treating residual waste with various WtE technologies is a viable option for disposal of MSW and energy generation. There are many factors that will influence the choice of technology and every region will have to properly assess its specific context to implement the most reasonable solution.

WtE is essentially an application of sound, proven combustion engineering principles to reduce & sanitize the residual solid waste after recycling and bio-composting the biodegradable component of the waste after pre-sorting to recover the energy. Municipal solid waste materials comprise organic and inorganic waste materials and adoption of suitable WtETreatment technologies is based on characteristics of waste. The advantages of gaining energy from wastes and additional benefits are 1) Quantity of waste reduced by 60% to 90%, based on the waste configuration and technology adopted for treatment. (2) Precise land for landfilling is gets reduced. (3) environmental Pollution reduction and (4) Reduce the cost of transportation of waste Selection of WtE technology will be basically dependent on the nature & capacity of received waste stream. A key factor is the energy content (calorific value) of the waste, which determines how much energy, can be extracted from it. For example, as a general rule, WtE incineration should only be considered if the incoming waste stream has an average net calorific value of at least 7 MJ/kg (i.e. combustion process is self-sustaining).WtE can bring many more financial benefits in addition to energy generation and some of fiscal benefits are attract Government incentives, Profitable treatment process, Developing Opportunities, international collaboration, Inspire youth, etc. WtE reduces the amount of waste material (quantity and volume) going for landfills. The et Calorific value of waste (MJ/kg) viz. Paper – 16, Organic material-4, Plastics -35, Glass & Metals -0, Textiles-19, Other materials – 11.

3.1 Efforts of Swachh Bharat Mission

The Swachh Bharat Mission (SBM), which purposes to make India a clean, green and open defecation free nation by 2019, needs to become a 'Jan Andolan' with participation from each participants/stakeholder. The SBM has to achieve the objective of 100% municipal solid waste processing and disposal by 2019 and this is objective is feasible once the Urban Local Bodies start considering the urban waste as a renewable material/resource. The confidence of meeting the target emerges from the fact that all waste processing technologies like waste to energy(WtE), from the basic to sophisticated have been harnessed in India itself and can be replicated with minimal re-adjustments suiting to specific sites and ULBs. As per the direction of Ministry of power with approval of Union Cabinet for power Tariff policy 2006, SBM can achieve 100% power procurement from WtE plants since WtE can prove this challenges and reserves. Solid waste management rules 2016 published by Govt.of India to make this more effective, and serving the initiative taken under SBM.

3.2 Methodology

Figure 6 shows mmethodology chart which describe WtE technologies and gives an overall picture of the available options. WtE technology mainly based type of waste, quantity of raw materials, suitability of method for energy generation, features of waste materials like composition & characteristics of waste and some standards, etc. The methods of WtE Technologies majorly classified as thermal, bio-chemical and chemical technologies

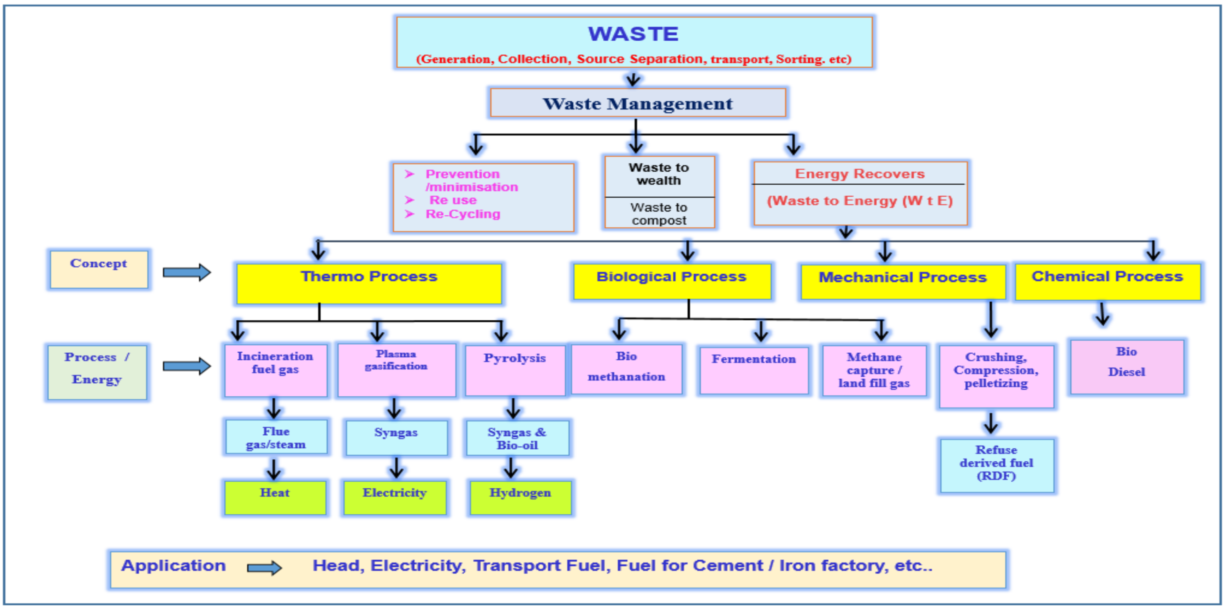

***Fig. 6** –WtE Technology Tree*

3.3 Optimal technologies for the energy generation from waste utilized in India

The WtE technology in India is still in its starting phase because the techniques for collection, treating and disposing of garbage are not appropriate. The United Nations centre reports appropriate technology options for regional development in India in collaboration with the housing and urban affairs ministry (Government of India) and the Environment Ministry (Government of Japan). Waste to energy technologies are detailed below.

3.4 Thermal technologies

Government of India recognized WtE as a renewable energy technology The destruction of solid waste by using heat energy is called thermal Technologies/treatment. there are many thermal processes viz. Incineration, Pyrolysis (syngas), Refuse derived fuel(RDF) and Gasification are some methods to convert waste into energy. In thermo-chemical conversion all of the organic matter, biodegradable as well as non-biodegradable, contributes to the energy output Net power generation potential (kW) = 14.4 x W and W is total waste quantity in tonnes

3.4.1 Incineration

Incineration involves burning of waste at high temperature at 700-1000oc in combustion chamber with presence of oxygen which result production of heat energy, fuel gas and remaining as ash and this method is most suitable for high calorific value waste materials. Incineration process mainly consists three stages like (a) Incineration, (b)Recovery of energy, (c) Control of pollution (Emission control equipment's). Stocker and fluidised bed type furnaces are generally available and used in incinerators. This process reduces the volume and weight of waste by 85 to 90% and 75 to 80% respectively [11]. The acidic gases, formed due to combustion, are neutralised (Dry & Wet Scrubber), The Particulate matter is captured (Cyclone Separator, Bag Filter). Jabalpur Municipal Corporation installed incineration plant with the processing Capacity of 600 MT and net Power Generation about 11.5 MW. Figure 7 shows various Waste to Energy Plants were installed in India.

3.4.2 Pyrolysis

Pyrolysis is the method by thermal technology of waste to energy which implies decomposition of organic fraction of waste in the absence of oxygen i.e., in the anaerobic environment which produce fuel gas called synthetic gas contains carbon dioxide, Hydrogen and Co2, CH4, residues of liquid & solids. The composition of Syngas is 41% of H2 ,30% of CO,16% of N2 ,8% of CO2 and 5% of others. This method is also used to generate a synthetic diesel (fuel) from plastic waste called waste plastic pyrolysis process which is more successful. Pune municipal corporation has installed pyrolysis plant and running successfully till date.

3.4.3 Gasification

Gasification is a type of thermal method for process of waste convert into energy that convert organic or fossil base carbonaceous waste materials into carbon monoxide, hydrogen and carbon dioxide at higher temperature in the presence of the limited quantity of oxygen. Gasification (WtE) Plant installed by Pune Municipal Corporation with the processing Capacity of 700 MT and net Power Generation about 10 MW

3.4.4 Refuse-derived Fuel (RDF)

This eco-friendly method of disposal of MSW by provides alternate fuel which can be used in boiler, Cement/Steel factories, Furnaces etc. Segregation of dry organic component of wastes from mixed MSW to produce fuel in the form of briquette/ pellets/ fluff and combination of same to generate energy. Process of RDF is Refuse material goes to primary crushing and drying. After drying, classification based on size i.e. removes foreign materials transferred into secondary crushing to reduces volume of waste and subsequently making as RDF Pellets (Process incudes shredder, Trommel and compressing) .RDF also be used in co-processing in Cement kilns, co-burning in coal fired power plants. In general RDF is simply storable, easily transportable and fuel used as alternate in industrial furnaces/boilers, etc. In India many successful RDF plants are there and some of plants located at Hyderabad, Jaipur and Chandigarh is already being supplied RDF as fuel in cement plants like Ambuja, Chettinad, Bharathi, Vasavadatta, Zuari, Ultra tech and many more.

Incineration Plant, Okhla,

RDF Plant, Narela

Incineration Plant, Jabalpur

RDF Plant, Ghazipur

Pyrolysis Plant, Pune.

Biomenthanation Plant, Solapur.

Gasification Plant, Pune.

Biomenthanation Plant, Chennai

***Fig. 7** Some of Waste to Energy Plants in India*

3.5 Biological technologies

In bio-chemical conversion, only the biodegradable fraction of the organic matter can contribute to the energy output and this technology is more safe, cost-effective and conservational free.Net power generation potential (kW) = 11.5 x W , as per the calculation 1000 tonnes of raw MSW with 55-65% organic matter/waste can generate about 10- 15 MW power energy, depending upon the characteristics and composition of waste

3.5.1 Biomethanation

Biomethanation is anaerobic digestion of organic waste which is biodegradable. There are laid in an enclosed drum/ container under environment controlled conditions of pH, moisture and temperature etc. The present organic fractions in the organic wastes are undergoes decomposition, hence there by generation of biogas which consisting mainly of methane and CO2. Balance material which contain high nutrients can be used as fertilizer. This method of biological technology has severe benefits like requirement of less land, generation of good amount of Energy and discharged sludge can be used as conditioner for soil. Biomethanation feed stocks are MSW, drain waste, Animal waste, Horticulture / plant residues & food wastes. The resulted biogas composition is methane (80-85%), carbon dioxide (11-13%), and Nitrogen (3-5%).

3.5.2 Fermentation

This fermentation method used for domestic and commercial /Industrial purpose to provide Bio fuel/gas from waste as effective management of MSW which acted by bacteria & yeast where oxygen is absent. Example fermentation of sugars in to ethanol followed by distillation. This fermentation is Low cost method and the process is single step. (11).

3.6 Advantages and Challenges of WtE technologies utilized in India

Table.4 shows various WtE technologies and their advantages & challenges

WtE Technology	*Advantages*	*Challenges*
Incineration	Immediate reduction in volume and weight by about 90% and 70% respectively, Stabilization of waste and Energy recovery. Relatively noiseless and odourless, Can be located within city limits, reducing cost of waste transportation.	Management of dioxins and furans formed in incineration
Pyrolysis	Immediate reduction in volume and weight & less space requirement, Stabilization of waste, Easy to operate, Pyrolysis of waste plastics is an upcoming technology for conversion plastics to either liquid fuels or chemicals. Residue @3%	Pyrolysis oil is unstable & needs further processing; Energy is distributed in 3 fractions.
Gasification	Immediate reduction in volume and weight, Environment friendly, Energy efficient ,Gasification is more efficient and environmental friendly technology than incineration for conversion waste into energy	Higher initial cost compared to incineration. Skilled labour is required. Air emissions.
Refuse-derived Fuel (RDF)	High calorific value of the waste. RDF is usually prepared in the form of pellet/ briquette/ fluff from dry high calorific value combustible wastes ,Process is self-sustainable with value addition.	Challenges are suitable for the areas where large amount of combustible waste is being generated.
Biological technologies	Energy generation, Reduced land requirement. Results in stabilized sludge which can be used as a soil conditioner and challenges are Suitable for only wet organic waste, System is sensitive w.r.t. ambient temperature, needs efficient O&M to control odor. This WtE technology is well recognized and proven technology, at the same time meet with waste in wet condition only	Suitable for only wet organic waste, System is sensitive w.r.t. ambient temperature, needs efficient O&M to control odor.Fire and safety measure , Leachate collection & treatment
Land fill	Least cost option, Reduced GHG emissions, Gas produced can be used as domestic fuel.	Greatly polluted surface runoff during rainfall and contamination of soil and water by pollution. Leachate collection & treatment

Finally, selection of Waste to Energy technology is based on quantity& Type of waste to be processed, Environmental factors (emission and minimize landfill) and Economy (Cost Vs. Benefit, Social & Financial), acquired energy recovery levels

3.7 Need of suitable types of waste for WtE technology

For Bio-methanation, wet biodegradable waste is required; for Combustion of RDF, dry high organic waste is required; for Gasification, organic or fossil based carbonaceous material is required; and for Pyrolysis, organic waste is required. Mass Burning of MSW is the only method i.e. incineration which does not require any segregation of waste and uses mixed waste. However, this method of Mass Burning is detrimental to the environment, and should not be resorted to on a mass scale.

Need of segregation of waste at source: Most of the above mentioned technologies require proper segregation of waste; however, there is lack of an efficient mechanism to segregate waste into biodegradable/dry/wet/ carbonaceous materials, etc. components. Hence there should be efficient mechanism for segregation of waste at the source as it has become a herculean task all over the country. So, proper training should be provided to municipal workers for segregation of waste and awareness and sensitization programmes should be conducted for the same to bring in behavioural changes among the public. The WtE conversion processes generally employed in India are thermal conversions processes such as incineration, gasification, pyrolysis, refuse-derived fuel and biochemical conversions processes such as vermicomposting, composting, bio-methanation or anaerobic digestion. Furthermore, the chemical conversion process such as transesterification is also practiced along with other methods to get biodiesel from vegetables and plant oils. Each one of the different technological options has its benefits and constraints, which guides in choosing the appropriate technology for a given local condition.

IV. WASTE TO ENERGY PLANTS STATUS IN INDIA

In India there are 209 composting plants ,207 vermicomposting plants ,82 bio-methanation plants and 45 refuse derived fuel plants under setup condition [7]. As per MoUD, there are 7 functional plants of 92.4 MW capacity, 4 non-functional plants of 40.6 MW capacity, 31 under construction plants of 241.8 MW capacity and 21 plants under tendering stage of 163.5 MW Capacity. Total power generation capacity of all WTE plants in India is 538.3 MW.Total of Power Generation Capacity =Functional (A) + Non-Functional (B) + Under Construction & others (C) = 538.3 MW

The Ministry of New and Renewable Energy (MNRE) provides Central Financial Assistance (CFA) for setting up of waste to energy plants utilizing agricultural waste, urban waste, industrial waste and Municipal Solid Waste (MSW) to generate power. In addition, the Swachh Bharat Mission under the Ministry of Housing and Urban Affairs also provides central assistance of 35% of the total project cost to all statutory cities/ towns as per the guidelines for Solid Waste Processing including waste to energy projects.

4.1 Making the Waste to Energy projects viable

To be able to make Waste to Energy projects financially viable, Municipality needs to offer incentives to developers with a “tipping fee” funded to the developer for 1000kgs of waste. Classification of waste at source and subsequent stages are important to create the system more competent for recovery of energy from waste. Collaboration of political institutions with technical teams for project clearance and rehabilitation of all rag-pickers should be on high priority. The waste to energy cost in India depends on the system but one can make it feasible by aligning objectives of all stakeholders, involving a suitable tipping fee and establishing proper financial pathways with a proper site to set up the entire waste to energy project.

4.2 Involving Environmental Aspects and Impacting of a Waste to Energy

MSW is an unavoidable by-product of the society and needs to be handled in an environmental friendly manner without causing any health hazards of living beings. Disposing of waste through landfills raises health hazards. There will be a good source of fuel from the wastes as the current landfill sites can be mined out, and the landfill materials can be used as fuel. Even though the WtE is an attractive technological option for waste management, combustion-based processes (incineration, pyrolysis, and gasification) for MSW treatment are a subject of serious debate throughout the world in these days. In the absence of adequate controls in WtE processes, dangerous pollutants may be discharged into the air, land and water which may affect human well-being and the atmosphere. Incineration-based techniques have been a subject of intense debate in the environmental, social and political aspects. Suitable safeguard and pollution control measures/devices further need to be incorporated in the design of each WtE technology to fully comply with the environmental regulations and safeguard of public health.

Table 5. *Waste to energy plants currently operational/under trial run [Source: MNRE, 2018]*

As on Date*	
No.of Functional plants	7
Production Capacity of functional plants (MW)	88.4
No. ofplants under construction	56
Production capacity of plants under construction (MW)	415

WtE Potential: 511 MW

State/Union Territory	From Liquid Wastes* (MW)	From Solid Wastes (MW)	Total (MW)
Andhra Pradesh	16	107	123
Assam	2	6	8
Bihar	6	67	73
Chandigarh	1	5	6
Chhattisgarh	2	22	24
Delhi	20	111	131
Gujarat	14	98	112
Haryana	6	18	24
Himachal Pradesh	0.5	1	1.5
Jharkhand	2	8	10
Karnataka	26	125	151
Kerala	4	32	36
Madhya Pradesh	10	68	78
Maharashtra	37	250	287
Manipur	0.5	1.5	2
Meghalaya	0.5	1.5	2
Mizoram	0.5	1	1.5
Orissa	3	19	22
Pondicherry	0.5	2	2.5
Punjab	6	39	45
Rajasthan	9	53	62
Tamil Nadu	14	137	151
Tripura	0.5	1	1.5
Uttar Pradesh	22	154	176
Uttaranchal	1	4	5
West Bengal	22	126	148
Total	**226**	**1457**	**1683**

No	State	Composting	Vermi-composting	Bio-methanation	RFD	Incineration / gasification
1	Andhra Pradesh	0	18	8	0	0
2	Assam	1	0	0	0	0
3	Delhi	1	0	0	0	3
4	Goa	7	0	0	0	0
5	Gujarat	0	93	1	3	0
6	Haryana	4	0	0	4	0
7	Jammu & Kashmir	0	2	0	0	0
8	Karnataka	104	57	27	4	0
9	Madhya Pradesh	11	0	0	1	1
10	Maharashtra	43	31	42	5	1
11	Meghalaya	1	1	0	0	0
12	Odisha	1	0	0	0	0
13	Punjab	0	1	0	2	0
14	Tamil Nadu	12	0	3	19	0
15	Telangana	10	3	1	3	0
16	Uttar Pradesh	13	0	0	4	0
	Total	208	206	82	45	5

4.3 Star rating for WtE Plants

Star rating devised to ensure holistic evaluation across entire SWM Chain for smart waste management system. The rating is based on 12 key components/criteria for awarding star rating system for WtE Plants to ULBs/MC/Private industries mainly:

(1)Door-to-Door Collection (2)Segregation at source(3)Sweeping of public, commercial and residential areas (4)Waste Storage Bins, Litter Bins and material recovery facility(5)Bulk Waste Generators compliance(6)Scientific Waste Processing, Scientific Land filling and C&D Waste Management(7)User Fees, Penalties, Spot Fines for littering and Enforcement to Ban on Plastic(8)Citizen grievance readdressal and feedback system(9)Eradication of crude dumping of garbage and dump remediation(10)Cleaning of storm drains and surface of water bodies(11)Visible beautification in the city(12)Waste reduction . Marks will be awarded and star rating shall be given based on score secured.

4.4 Role of PCB & MNRE

Since disposal of MSW poses problems of the pollution and health hazards, the PCBs are expected to take action for persuading the civic authorities in proper management of municipal solid wastes. These agencies have close linkage with ULBs /local authorities and carrying out necessary surveys and providing technological back-up for WtE. CPCB and SPCBs at national and state levels are to disseminate information and create awareness among the concerned authorities and public at large. Ministry of New and Renewable Energy (MNRE) is working for development of R & D units, setting up pilot demonstration projects in various cities, providing subsidies and have good co-ordination with experts for setup waste to energy projects. In India MNRE has coordinated and being coordinating for installation of many Waste to energy plants in different cities.

MNRE, GoI, said that the Ministry's focus is on energy generation from urban, industrial, and agricultural waste/residues, municipal solid wastes, vegetable and other market wastes, slaughterhouse waste, and industrial wastes and effluents. This will help WtE to produce electricity and reduce pollution and solve the problem burning of paddy straw by generating bio-CNG. since the inception of 'Swachh Bharat Mission' in 2014, the Ministry has already supported around 180 projects mainly based on production of bio-CNG/ biogas for various energy applications in industries and transport sector. The three major waste-to-energy projects of 52 MW, based on Municipal Solid Waste (MSW) have already been installed and running successfully in Okhla, Ghazipur, and Narela-Bawana in Delhi, which help in converting solid waste to electricity.

4.5 Constraints faced by WtE

The Major Constraints faced by the Indian WtE Sector and the growth of this sector has been affected on account of the following limitations/ constraints:

- WtE technology is new concept for India till date. Awareness to enhance segregation, Rapid urbanization and lack of appropriate level funding
- Coordination deficiency between Centre Govt. and State Govt. in implementation of WtE
- The major issues are segregation of municipal solid waste (wet, dry, others) and compliance of MSW Rules 2000 by the MC/ULBs, causes non-functioning of WtE plants at many places
- Equipments/Machineries for proven WtE technologies are required to be imported, its contribute financial burden and considerable time delay. The costs of the project for biomethanation technology are reasonably high.
- As most wastes sent to the WtE plants are unsegregated, they also have high inert content (inert materials like soil, sand, grit, etc). These wastes are not suitable for burning, and therefore to burn them, additional fuel is required which makes these plants expensive to run, there is no proper leachate collection and treatment system cause pollution.

4.6 Cost analysis

The Comprehensive Tariff Order for MSW based Power Plants issued by State Electricity Regularity Commission (SERC-TN) vide Order No. Order No. 3 of 2017, dated 28-03-2017, MSW power tariff is computed with reference to the determinants tabulated below. The tariff works out to Rs.6.16/- per unit of power generation without Accelerated Depreciation (AD) benefit. The AD benefit component of the tariff is Rs.0.10 per unit. The tariff for the generators availing AD benefit will be the tariff arrived at after deduction of AD benefit from the tariff as determined below. SERC, Tamil Nadu has carried out a detailed analysis of the existing policies/procedures and commercial mechanisms in respect of power generation from municipal solid waste power plants. [18].Table 6 shows cost analysis of WtE technology

Table 6. *WtE cost analysis [Source:TN SERC]*

Sl.No	Tariff Components	Values
1	Capital Cost	Rs. 16.00 Crores/MW
2	Life of plant and machinery	20 Years
3	Plant Load Factor(PLF)	75%
4	Debt-Equity ratio	70:30
5	Term of loan and interest	10 years with a moratorium period of one year. Interest at 11.00%
6	Return on Equity	20% (pre-tax)
7	Components of working Capital	a) O & M expenses at one month and b) Two months Receivables
8	Rate of interest for interest on working capital	11.50%
9(a)	O and M Expenses for plant and machinery on 85% of the capital cost	5.5% with an escalation of 5.72% from 2nd year onwards.
9(b)	O & M Expenses for land and civil works on 15% of capital cost	0.90% with an escalation of 5.72% from 2nd year onwards.
10	Description	4.5% SLM on 85% of the capital cost
11	Auxiliary Consumption	15%
12	Discount rate	9.24%
13	Levellised Tariff without AD	Rs. 6.16/- per unit
14	Levellised Tariff with AD	Rs. 6.06/- per unit

The CERC has notified general tariff for WtE of Rs. 7.90 per unit of power and Govt. has mandated 100% procurement of power generated from WtE plant. These initiatives will ensure financial viability of setting up of WtE plants in India. Compared to other sources of energy, WtE is imperative and protect public health and environment.

V. RECOMMENDATION AND CONCLUSION

5.1 Recommendations

Following are various recommendations that evolve from this study to improve the Waste to Energy technology and existing MSWM practices in India:

1 Need for the change in the habits of the people to ensure effective waste collection and segregation, citizens should be educated on effective waste management so that it would be easier for the WtE to process the waste. Efficient Solid waste management system will help in making India is cleaner and greener.

2 Volumes, quality, availability, characteristics of waste and technology choices related information, should be readily available for proper waste management using WtE.

3 Manufacturing of non-recyclable polyethylene bags (Single use plastic) should be banned because these waste are not suitable for recycling/recover energy.

4 Government should take initiative to encourage school/college/Universities to take up waste management in its curriculum as one of subject for public awareness and school childrens asked to visit IMSW management plants to know about waste, waste management, waste to wealth and Energy techniques, etc.,

5 Cost effective WtE technologies shall be invented through dedicated R&D of waste management to reduce capital and maintenance of WtE plant in India

6 Rules and regulation for Incentives/subsidies for WtE plants should be simplified/hassle-free and enough financial assistance provided to the MC/ULBs in waste management and implementing WtE technology

7 Environmental impacts and public health concerns should be considered during the selection of techniques/technologies of WtE. More number of expert/professionals in waste management technology should made available for effective waste management and cost effective implementation in India.

8 The Swachh Bharat Mission should concentrate/give importance the WtE technologies like on solar/wind power. ULBs/MC are cooperating with the WtE plant's administrators and officials for smooth and effective solid waste management in their cities/town, etc.

9 WtE plants should follow relevant Indian/International standards for healthy MSWM.Maximum times WtE plants receive poor quality/quantity of wastes in which generation of energy is not possible, and the result is unsatisfactory.

10 Improve waste separation/classification and use appropriate waste for WtE technology and moisture content in the waste lowers the efficiency of the technology and produce dioxins

11 Facilities gives to MSME entrepreneurs should also extended to WtE industries to improve interest and number of industries. Some suitable equipment utilizing clean technology to assure the removal of garbage without contamination of the atmosphere and considering emission standard, ought to be invented which should be suitable for using at any locality.

12 Govt. should arrange meet/conference periodically on "Swachh Bharat", Global investors meet to guarantee accessibility of land, labour, and funds in the WtE sector. Create WtE commission of India for clearance of WtE plant and management of existing plants

13 Govt. shall encourage design & manufacture of machineries indigenously to reduce cost of machinery. Tax exemptions shall be provided to these machineries. Govt.should identifies sites for IMSWM system and need for development of expertise and introduces courses in education for waste management to be encouraged.

14 Special privileges for workforce engaged in waste management works like Incentives, Bonus, PF, ESI, Insurance, safety gadgets, etc., and made arrangements for automation of all WtE activities to minimising labour involvement/risk.

5.2 Conclusion

From the above study it is strongly felt that the principle of Reduce, Reuse, Recover, Recycle and Remanufacture (5Rs) should be adopted and after making serious efforts to minimize waste, all components of MSW shall be utilized in a manner, such that the full potential of the waste is tapped. To achieve this segregation of waste at source and subsequent storages is necessary to attain this object. WtE techniques deliberated above offers harmless, economical, environment friendly disposal of MSW, accepted publically and reduce the land fill area/volume & prevent pollution. So suggested that proper training to be provided to municipal workers for segregation of waste (Bio-degradable, Non Bio-degradable, Dry waste) and awareness and sensitization programmes should be conducted for the same to bring in behavioural changes among the public and must be made aware Education campaigns related to solid waste separation at source places to make WtE more efficient, effectively manage MSW to full fill the objectives of zero waste to land filling.

The WtE technologies for production of electricity from MSW need to be cost competitive with other options in market. In order to improve the economic viability of existing WtE that process MSW, identified that number of areas where R & D could have a meaning full impact and research has to made utilisation of mixed solid waste, increase the calorific value of a waste, moisture reduction for successful MSW management. Cost analysis of WtE technologies and WtE technology not only support generation of electricity from waste but also help in reduction pollution and also address the issue of burning paddy straw by producing bio-CNG also discussed.

Suitable safeguard and pollution control measures/devices further need to be incorporated in the design of each WtE technology to fully comply with the environmental regulations and safeguard of public health. ULBs / MC should develop 'Green belt' with thick rows of selective plant species bearing flowers with strong fragrance along the periphery of waste dumping yard to absorb excess carbon dioxide and other toxic pollutants including ash and also provide considerable amount of oxygen. WtE technologies reduces the waste volume by 90% and the remaining residue can be safely disposed off in land filling and prevent GHG, reduce pollutants and stimulate the development of green technologies. Role of state/central PCB, MNRE, MoUD, MoEF&CC and SBM are involved for MSW (WtE) is very important for development and sustainable SWM system in India. But a monitoring committee consisting of representative of above agencies at each level should suggest suitable method and technology to be adopted to make WtE plant successful and viable.

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