Sustainable Waste Management Through Waste to Energy Technologies in India-Opportunities and Environmental Impacts

Charles Rajesh Kumar. J*‡, Mary Arunsi. B**, Jenova. R***, M. A. Majid****

*Department of Electrical & Computer Engineering, College of Engineering, Effat University, PO Box 34689, Jeddah 21478, Saudi Arabia

**Chinmaya Mission Hospital, Indira Nagar, Bengaluru, Karnataka-560038, India

***Government Primary Health Centre, Mulanur, Dharapuram, Tirupur, Tamilnadu-638106, India

****Department of Electrical & Computer Engineering, College of Engineering, Effat University, PO Box 34689, Jeddah 21478, Saudi Arabia

(ckumar@effatuniversity.edu.sa, dr.maryarunsi@gmail.com, jenorj@gmail.com, moabdulmajid@effatuniversity.edu.sa)

‡ Corresponding Author; Charles Rajesh Kumar. J, Department of Electrical & Computer Engineering, College of Engineering, Effat University, PO Box 34689, Jeddah 21478, Saudi Arabia, Tel: +966538658143,

Fax: +966126377447,ckumar@effatuniversity.edu.sa

Received: 12.01.2019 Accepted:20.02.2019

Abstract- The advancement in waste to energy (WTE) technologies in India economically provides an optimal solution for the restoration of power and heat and helps in fighting the rising energy demand. These technologies decrease waste volumes, environmental influence, threats to public health and dependence on fossil fuels for power production. As of 2018, more than 62 million metric ton (MTs) of waste is produced yearly in India and the same is expected to increase to 165 million MTs by 2031 and 436 million MTs by 2050 respectively. The land required for the dumping of the 62 million MTs of untreated waste is around 1,240 hectares per year, and the requirement is expected to expand to 66,000 hectares of landfill per year for the projected wastes in the years to come and besides the country also requires a task force to treat these wastes by utilizing proper technologies. India has an estimated potential of WTE of about 2.554 GW from municipal solid waste (MSW) and about 1.683 GW from urban and industrial wastes. The existing WTE plants are an attractive technological alternative for managing wastes, but the pollution caused by these plants is a serious concern and pose a threat to the environment. The current policies, programs, and management structure do not sufficiently address the immediate hurdles of managing the projected waste due to a shortage of logistics and significant planning, inadequate funding, unsuitable technical attentiveness, and inappropriate resource management. The primary intent of this manuscript is to show the potential of the WTE in the country, including the possible technologies, job, and business opportunities and lastly the environmental influence. Also, the policies that need to be improved, evolved or modified to encourage WTE industry are suggested along with a few recommendations for the course of action in the WTE sector that can support the investors, WTE project developers, suppliers, decision makers and the policymakers for further better management and planning.

Keywords Waste Management, Waste to Energy (WTE); Municipal solid Waste (MSW); Industrial Waste; Urban Waste; Biomedical Waste; Barriers; Policies; Guidelines; Opportunities; Environment Impacts.

1. Introduction

When compared to the past, the present pattern of living has changed with a significant increase in the number of industries, a fast-growing economy rate and also a substantial expansion in the population living in the urban area which has ultimately contributed to the humongous volumes of waste generation. This increase in the waste generation has led to undesirable pollution in the environment creating a negative impact on public health. Chaotic landfilling, indiscriminate dumping of wastes and mass burning are the conventional techniques of disposal of wastes followed in India which has resulted in unacceptable environmental and health consequences. The country has however recognized the unfortunate consequences and the ill-effects of such techniques being practiced and has come forward to accommodate eco-friendly and affordable solutions for the dumping of wastes. There is an ever-increasing need for energy despite the increasing costs of oil & other fossil fuels with depletion of fossil fuels. The energy demand, in particular, the electricity generation, has resulted in the creation of fossil fuel based power plants that let out abundant greenhouse gas/carbon emission into the environment which has resulted in global warming and changes in climatic conditions [1]. Like many developing nations, the government of India is working towards decreasing such undesirable impacts of global warming by making out policies conducive to encourage renewable energy generation in India. The country is bestowed with several kinds of renewable energy sources such as solar, biomass, small hydro, wind, and biogas. Urban, municipal and industrial wastes could also be beneficial sources of energy when guaranteed safe disposal.

Some of the major types of solid wastes include municipal solid waste (MSW), hazardous wastes, industrial wastes, agricultural wastes, and bio-medical wastes. The growing waste generation and its unscientific disposal methods are heading to the discharge of GHG (methane, CO_2, etc.) in the atmosphere. Safe waste management is essential for the green economy and sustainability intentions of both government and the private sectors. Renewable waste materials from agriculture, (crop debris, livestock wastes, abattoir wastes, bulk forest wastes, etc.) [2,3,4,5,6] industries (paper and pulp, bagasse, press mud, contaminated petroleum or synthetic oil, water in oil, oil in water, tarry residue waste, coal tar, heavy metals, a metallic chemical element both lethal and dangerous)[7,8,9,10,11,12,13] and domestic sources(bottles, cans, clothing, compost, disposables, food packaging, food scraps, newspapers and magazines and yard trimmings) [14,15,16,17,18] are convertible to useful energy forms like bio-hydrogen, biogas[19], bio-alcohols, etc., through WTE routes for sustainable growth of the world. Total solid wastes are being produced annually as by-products through industrial, municipal, agricultural, mining and other processes in the country [20]. As of November 2017, MSW generation is around 1,45,626 MT/day and MSW per annum being 53.153 million MT. It is estimated that by the year 2021 the waste generation would increase to 71.15 million MT/year and 160.96 million MT/year by 2041 respectively. Together with the prevention and recycling measures, the WTE sector contributes significantly to attaining the intentions of waste management. The promising WTE conversion technologies include biochemical conversion, landfills and thermal conversion methods such as incineration, pyrolysis [21,22], and gasification [23]. The ultimate recovery outcomes of these technologies are electricity, fuel gases, heat, solids, and liquids. In practice, combinations of two or more of these methods may be employed.

The potential of energy recovery from urban and industrial wastes is about 1683 MW which includes 226 MW from liquid wastes and 1457 MW from solid wastes. The potential for power generation from MSW is 500 MW. It is predicted that by 2020 the energy generation potential of MSW in India will be 2836.16 MW using 135702 tons of waste per day [24,25,26,27]. Currently, as per 2018 records, India stands the fifth position globally in renewable energy (wind, solar, biomass, small hydro and WTE) capacity next to China, the United States, Brazil, and Germany [28] with an installed capacity of 74,081.66 GW. As of December 2018, the Central electricity authority of India (CEA) has reported that the cumulative installed capacity of WTE is 138.30 MW [29,30]. In 2017-18 the total renewable electricity generation was 101839.48 MU from 70 GW installed capacity and the generation from WTE was 358.45 MU from 138.30 MW installed capacity. As on 31.12.2018 (2018-19), the total production from renewables was 97924 MU, and WTE generation was 319 MU. The government deserves to be on the path for reaching its 175 GW target by 2022. With market forces placed into operation by a clear policy intention, India is anticipated to reach its climate targets conveniently. WTE is anticipated to see robust growth and positive policy support by the government going ahead as conventional fossil fuel power projects are meeting increasing transition uncertainties. The ministry is actively encouraging the generation of energy from waste by granting subsidies and incentives for the projects. The initiatives provided by the Ministry of new and Renewable Energy (MNRE), Government of India, does not only promote the generation of energy from the waste but also assists in decreasing pollution. The Ministry also promotes all technological possibilities for establishing projects for recovery of energy from wastes [31]. The growing waste volumes in the country are forming a new business section for the value chain players – making solid waste management (SWM) collectively another industry practice. The renewable energy sector is providing business opportunities in each segment in the country[32].

There are a lot of health-related issues documented because of poor waste management techniques followed in the country. The public health concerns include infections in the lungs, nose, throat, sinuses, chronic lung disease, and breathing difficulties, infections due to bacteria, hemoglobin deficiency, decreased resistance to diseases and allergic reactions resulting in poor health among the public[33]. The available technologies that support waste management are pyrolysis, gasification, and incineration. Incineration based methods, anaerobic digestion [34], bio-methanation, refuse-derived fuel (RFD), landfill gas recovery and composting are employed in large volume and has created severe concerns in the political, social and environmental investigations. Proper disposal methods which maintain the balance between economics, technology and ecology are mandatory. Continuous R&D to implement advanced techniques, equipment and tools for the WTE are essential to obtain the balance. The recent day's biomedical wastes are emerging as a topic of rising concern relating to public health because of their undesirable effects in the environment [35].The biomedical wastes are managed by various technologies such as incineration, autoclaving, etc. However questions related to the serious environmental concerns continue to rise due to these methods [36,37,38]. From the various problems and consequences presented by biomedical wastes, the need for strict biomedical waste disposal methods and waste management rules are required to be implemented immediately to protect the environment and the public health [39].

Many barriers such as inappropriate waste recovery and disposal methods are forming an obstacle to the development of WTE [40,41]. The growth of the WTE sector has been influenced by many barriers and the most appropriate techniques from waste acquisition to disposal are not being followed. Further, the essential difficulties can be listed as political, economic and technological. Inadequate funds, the lack of regular national policy and legislation as well as of complete data collection and assessment are some of the challenges confronting implementation of modern waste treatment technologies including WTE solutions. Analysis and discussion of such limitations may be beneficial towards planning the future introduction of this kind of technologies in the country, especially regarding the new power sector's perspectives in India [42]. By supporting communities in Indian cities for proper waste management, one can acquire various advantages. Proper waste management and WTE can produce renewable energy with a clean and healthier ecosystem, raising the quality of life in all areas. WTE can drive to employment opportunities for several people in all communities decreasing the unemployment rates. The diminishing landfills can free up precious land, enhance the air quality and minimize the bad odor. The entire amount of waste is reduced by nearly 60% – 90% depending on the composition and technology utilized for processing and handling. With WTE, there will be a reduced land requirement needed for landfilling of waste.

The expenses towards transportation required in carrying waste to landfills will be reduced and will also result in a massive decrease in environmental pollution. Along with energy production from the waste, the slurry formed from the WTE processes deliver as an effective fertilizer. Improvements in WTE technology will undoubtedly help in fuel growth in the industry, and this will have an impact on the region and emerging economies in India.

In 1987, a large scale bio-methanation project (300 TDP, INR 250 million) in Timarpur, New Delhi was out of operation within six months of installation. In 1999, RDF plant was commissioned (power generation 6.6 MW) which could handle 1000 TPD but received only 700 TPD, and a plant in Vijayawada with a capacity of 500 TPD to produce six MW of energy was commissioned. Currently, none of these plants are in operation. Ten mechanical and biological treatment aerobic composting projects in the 1970s and two RDF projects in 2003 have encountered initial failure.

In this research, we have examined and suggested various job opportunities for the citizens of India in the WTE sector. The environmental concerns and impacts of WTE and a safe way for biomedical waste management using WTE are addressed. The reasons for failure in WTE in India such as improper waste collection methods, lack of public participation, lack of source segregation, litigation issues, quality of waste, viable technologies, insufficient financial support and lack of policies are identified.

If India concentrates on economic and logistical planning, the failures can be avoided. Furthermore, the country should look to strengthen the policy framework which may otherwise lead to the citizens, industry participants and investors being against the process. Based on the research outcome we have suggested recommendations to guide future policies and make WTE a viable option for waste management and energy production in India.

2. Types of Waste

Several kinds of wastes from agricultural (animal wastes and plant), industrial (slaughterhouses, pulp and paper, sugar refinery, confectionary waste, tanneries, and dairy wastes) and residential (garden waste and kitchen waste) sectors are the potential renewable energy sources to achieve sustainability and for a switchover to WTE programs [43]. The increase of population, growing urbanization and improving standards of living have added to a raise both in quantity and variety of wastes produced by different activities. Broadly, waste can be categorized as urban waste, industrial waste, biomass waste, and biomedical waste which is shown in Table 1 [44,45].

3. Waste Generation in India

The population of India is approximately 1.3 billion and each day a single person is generating 0.5 kilograms of waste. A massive pile of garbage is landfilled in an unsanitary manner.

3.1. *Population Growth and Waste Generation*

As of November 2017, the waste generation was around 53 Million metric tons per year and 145626 tons per day in India. The country is expected to produce 71.15 Million MT by 2021,107.01 Million MT by 2031, 31.24 Million MT by 2036 and 160.96 by 2041. Similarly, the projected global waste generation for the year 2050 is 27 million MT which is shown in Table 2.

China and India play a vital role to add to worldwide waste generation [46,47,48,49]. According to the research projections by 2025 around 0.7 kg waste per person is expected to combine into total waste generation in India. It is observed that there will be an increase of at least 4 to 6 times compared to the year 1999. These findings show the effect of population increase and waste generation.

Table 1.Classification of Wastes [44]

Waste from Urban	Municipal Solid Waste: 1. Paper, Glass, Metals, 2. Man-made polymers such as epoxy, Teflon, polyethylene, polyester, nylon, cords, coils, gadgets, etc., 3. Inerts (stones, sand, and pebbles, etc.), 4. Hides and leather discard, 5. Pharmaceuticals wastes (tablets, , lotion,ointments, etc.), 6. Sanitary and Rags ware, 7. Kitchen wastes (vegetable and Fruit peels, raw and processed food ingredients, etc.). Sewage: 1. Bulk excretory matters (Feces and urine), 2. Wastes from the body (necrosis, spit, tears from the eye, sweating, oil, fat, lubricant, nails, and hairs of the body, etc.), 3. Bath wastes, 4.Laundry wastes (Detergent and soap precipitates).
Waste from Industry	Solid: 1. Paper and pulp waste, 2. Bagasse (sugarcane, bamboo, etc.), 3. Pressmud, 4. Brine mud, 5. Metallurgical slags, 6. Gypsum, 7. Fly ash, 8. Oil sludge, 9.Synthetic fibers (Scrapings of nylon, polyesters, etc., Liquid: 1. Non-soluble of miscible oil, paint with emulsion, waste from oil, 2. Tarry waste and residues /High-density (High automatic weight) metals, 3.Industrial effluents (textile dyes), 4. A mixture of liquid with manure, a mixture of a liquid with cement /clay slurry /crushed liquid and solid, 5.Byproduct after cheese/casein manufacture from milk (dairy plants), 6. Stillage/spend wash from alcohol distillery industry along with ethyl alcohol, molasses, and yeast. 7. Contaminants from dissolved organics.
Waste from Biomass	1. Crop debris (stalks, straws, cobs, husks, oil cakes, shells, pods, etc.), 2. Diary forms from where we get meat, milk, and egg and the corresponding wastes from the animals and birds, 3. Abattoir wastes (flesh, bones, organs, blood, etc.), 4. Bulk forest wastes (wood, stubbles and Humus, 5. Wastes from forests wood wastes, leaves, grains, spores in trees, 6 Alternative forest wastes (algae and bacteria from cultured systems).
Waste from Biomedical	1. Anatomical wastes and pathological waste (muscles, glands, body portions), 2.Veterinary wastes from animals, 3. Laboratory reagents, 4. Discarded medicines and cytotoxic drugs, 5. Fluids from the body such as plasma, urine, spit, 6. Surgical wares, 7. Incineration ash, 8. Microbial cultures (Pathogens, etc.).

Table 2. Predicted Population increase and overall impact on waste production [49]

Year	population (Billion)	per capita generation (Gram per day)	total waste generation (Million MT per year)
2001	0.1973	439	31.63
2011	0.2601	498	47.30
2021	0.3428	569	71.15
2031	0.4518	649	107.01
2036	0.5186	693	131.24
2041	0.5954	741	160.96

3.2. State-wise Solid Waste Generation inUrban Areas

Table 3, presents the state wise solid waste production in urban regions, as of November 2017. It shows that Maharastra generates the highest waste, followed by Tamilnadu, Uttar Pradesh, Gujarat, and New Delhi. In Maharashtra, the critical industries generating wastes, which have tremendous potential for power production, include sugarcane press mud, paper & pulp, distilleries, poultry, dairy industry waste, abattoir, etc. The total estimate of energy potential from industrial wastes is 350 MW (MNRE estimation was 287 MW). This potential is illustrated in the "MEDA-2012-Perspective Plan" by Tata Energy Research Institute, New Delhi (TERI). Waste production due to domestic, commercial and industrial actions. The post-industrial revolution era witnessed accelerated urbanization and industrialization resulting in large scale garbage production concentrated at particular urban centers.

Vast amounts of chemical degradable waste along with organic degradable waste are being produced from the industries in Maharashtra. Inappropriate disposal of waste from industries creates pollution in the environment. Therefore, the government has determined to encourage energy production from wastes. Currently, there are 65.75 MW WTE plants are in operation in India utilizing MSW [50].

According to the Ministry of Urban Development, government of India in 2014, MSW generation is 133000 MT/day, Total waste collected is 91000 MT/day, waste littered 42000 MT/day, MSW treated is 26000 MT/day and landfilled (crude dumping) 66000 lakh MT/day. India needs 1,240 hectares of extra valuable land every year to include untreated solid waste. The calorific value ranges from 800 Kcal to 1100 Kcal and moisture content 40% to 50% [51].

Fig. 1 shows the waste generated in India per year (MTs). It shows that Total of 62 MT created which includes 7.9 MT of hazardous, 5.6 MT of plastics, 1.5 MT of e-waste, 0.17 mT of biomedical waste and 46.83 MT are other wastes.

Table 3. State-wise Solid Waste Generation in urban areas, MNRE, November 2017 [50]

No	State	Total waste generation per day metric ton per day(MT/D)	Total waste generation per day million MT /annum
1	Andhra Pradesh	6525	2.382
2	Andaman & Nicobar Islands	115	0.042
3	Arunachal Pradesh	181	0.066
4	Assam	1134	0.414
5	Bihar	1192	0.435
6	Chandigarh UT	340	0.124
7	Chhattisgarh	1959	0.715
8	Daman & Diu	23	0.008
9	Dadra & Nagar Haveli	58	0.021
10	NCT of Delhi	10500	3.833
11	Goa	240	0.088
12	Gujarat	10145	3.703
13	Haryana	4514	1.648
14	Himachal Pradesh	342	0.125
15	Jammu & Kashmir	1792	0.654
16	Jharkhand	2451	0.895
17	Karnataka	10000	3.650
18	Kerala	1576	0.575
19	Madhya Pradesh	6424	2.345
20	Maharashtra	22570	8.238
21	Manipur	176	0.064
22	Meghalaya	268	0.098
23	Mizoram	201	0.073
24	Nagaland	342	0.125
25	Odisha	2460	0.898
26	Puducherry UT	495	0.181
27	Punjab	4100	1.497
28	Rajasthan	6,500	2.373
29	Sikkim	89	0.032
30	Tamil Nadu	15547	5.675
31	Telangana	7371	2.690
32	Tripura	421	0.154
33	Uttar Pradesh	15500	5.658
34	Uttarakhand	1400	0.511
35	West Bengal	8675	3.166
	Total/ Average	145626	53.153

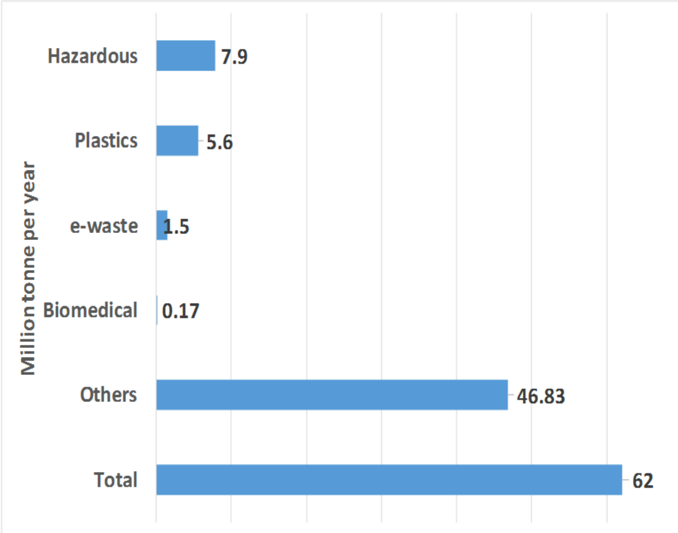


Fig.1. Waste generated in India per year (MTs) [51].

4. Technologies for the Energy Generation from Waste

The primary treatment of waste provides energy in the form of electricity or heat. WTE makes this energy recovery through various techniques such as thermal conversion, biochemical conversion, thermochemical conversion, and electrochemical conversion. All these techniques depend on the quality of waste, the quantity of waste, aspired form of energy, customer requirements, rules, and standards of the environmental ministry of the country and financial conditions of the private or government companies who are performing the WTE [52,53].

The various technologies used to generate energy from waste are compiled in Table 4. Thermochemical methods include incineration, thermal gasification, and pyrolysis. Biochemical processes are fermentation, anaerobic digestion, landfill with gas capture, microbial fuel cell. The chemical process is esterification.

The Incineration processes include mass burn, co-combustion, refuse-derived fuel, and the end product is heat, power and combined heat and power. The end product of thermal gasification is hydrogen, methane, and syngas. The end product of pyrolysis is char, gases, aerosols, and syngas.

The fermentation process is dark fermentation, photo-fermentation, and the end product are ethanol, hydrogen, and biodiesel. In anaerobic digestion and landfill with gas capture the end product is methane.

In esterification, the end products are ethanol and biodiesel [54]. Fig.2 shows the various techniques linked with different waste materials. For example, inert materials are managed using landfills, plastic paper metals are recycled, and wet fractions are treated using anaerobic digestion [55].

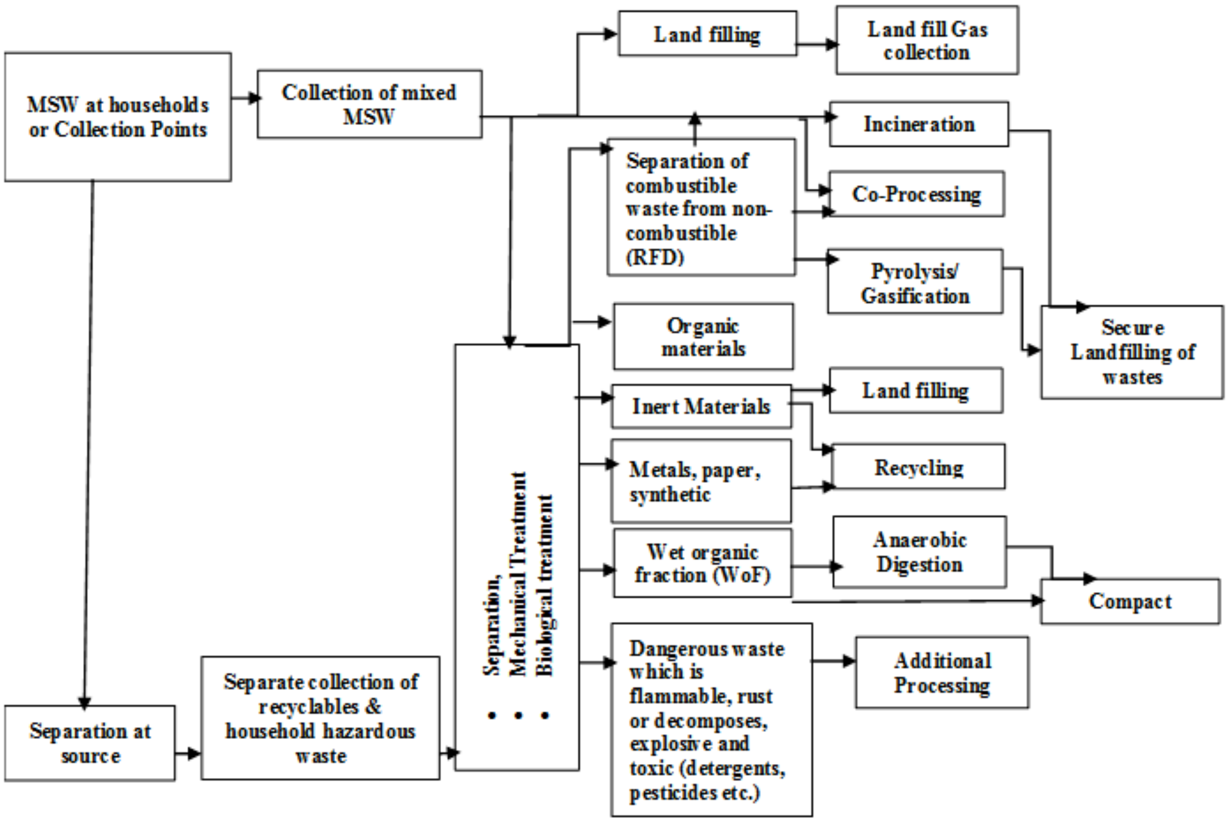


Fig.2. Summary of the various techniques linked with different waste materials.

Table 4. Current Technologies for waste to energy [55]

Technology	Method	Processes	End product
Thermo-chemical	Incineration	Mass burn: Burning the waste at a temperature above 1000 oC	Heat, Power, combined heat and power.
		Co- Combustion: with coal, biomass	
		Refuse-derived fuel: using pre-treated fractions of waste with higher and more stable energy contents	
	Thermal gasification	Conventional: Temperature of 750 oC	Hydrogen, methane, syngas
		Plasma arc: Passing waste into kin at 4000-7000 oC. Waste products are vitrified.	
	Pyrolysis	The temperature of 300-800 oC, at higher pressures and in the absence of oxygen	Char, gases, aerosols, syngas
Biochemical	Fermentation	Dark fermentation: Organic waste is treated with bacteria in the absence of a light source	Ethanol, hydrogen, biodiesel
		Photo-fermentation: Organic waste is treated with bacteria in the presence of a light source	
	Anaerobic digestion	Conversion process carried out by micro-organisms in the absence of oxygen	Methane
	Landfill with gas capture	Landfill with gas capture: extraction from existing landfill sites, by the natural decomposition of waste	Methane
	Microbial fuel cell	Microbial fuel cell: A catalytic reaction of nature microorganism and bacteria to convert the chemical energy content of organic matter.	Power
Chemical	Esterification	The reaction of acid and alcohol to create an ester	Ethanol, biodiesel

Table 5. Analysis of critical aspects of Current Technologies for waste to energy for nonhazardous Industrial waste [56]

Criteria		Incineration	Anaerobic Digestion	Gasification/Pyrolysis
Waste feeding for the WTE technology-feedstock for the power plants	Liquid waste from industry	Not apt	Apt	Not apt
	Solid waste from industry	apt	Not apt	apt
	Liquid waste from urban	Not apt	Apt	Not apt
	Solid waste from urban	Apt	Apt	Apt
	Liquid waste from farm	Apt	Apt	Apt
	Solid waste from farm	Apt	Apt	Apt
Technology innovations allowing the organized environment	Industry area	established	established	Developing
	Urban area	established	established	Developing
	Farming area	established	established	established
	Efficiency of energy	85-90% .The percentage depends on the heating value or calorific values	85-90% Percentage depends on evaporation of volatiles	85-90%. Percentage depends on the heating value or calorific values
Set of conditions for operating system/process	Specification of the system and system configurations	Composite	Not complex	Composite
	The versatility of the process	Below average	Average	Below average
	Modularity in design	Available	Available	Available
Capital expenditure and expenditure on O&M	Relative capital expenditure	Extremely expensive	Not extremely expensive	Extremely expensive
	Expenditure on O&M	High expensive	Low expensive	Limited expensive
	Ability to work successfully in terms of finance	Expensive due to the downstream and air contamination hence not much viable.	Immediately Viable	Changes Considerably
	Commitments of captive power	Notable (25-30%)	Moderate (5%)	Unsteady (5-20%)
	Space required to build the plant	Large space	Small space	Small space
Consequences on the ecosystem		Can be reduced with costly WTE technologies	Not much	notable degree of control is possible
Interaction of social and economic determinants	the quality of being accepted by the people	Not completely adequate	adequate	adequate
	Clearance of water	Ash to landfill problems	sludge stabilization problems	Problem with ash

4.1. Analysis of critical aspects of WTE technologies for non-hazardous Industrial waste

Table 5, shows the analysis of important aspects of current technologies for WTE for nonhazardous industrial wastes. The Table describes the various criteria such as feedstock, technology features, technology status, operating conditions, capital cost, operation and maintenance cost, environmental impacts and social, economic impacts. This analysis covers the incineration, anaerobic digestion, and gasification and, pyrolysis. It includes the suitability of the technology, system configuration, and process flexibility. Incineration and gasification are complex system configuration.

In commercial viability, anaerobic digestion is readily viable compared to others. Environmental impacts of Incineration compared to others can be minimized but requires expensive technology investments [56].

4.2. 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 is not appropriately performed. 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).

The optimal technologies identified for processing waste to generate electricity/heat in India are bio-methanation for biodegradable waste (wet), conventional microbial windrow, mechanized, vermicomposting for biodegradable waste (wet), preparing briquette, pellets, fluff as refuse-derived fuel. Incineration, pyrolysis, gasification for combustible wastes of high-calorific value (dry) and fuel oil from plastic wastes [57].

A combination of technologies as mentioned earlier has been recognized based on the quantity of population, the amount of biodegradable waste generated (percentage), the percentage quality of biodegradable waste generated are considered. Furthermore, technology consideration includes value-added products and by-products quantities expected.

Establishing a standalone waste to energy plants is possible with cities which can produce 1100 tons per day (TPD) of municipal solid waste having 2 million and above population. It is possible because the thermal route is suitable to set up the WTE plant. To optimally use the biodegradable wastes combination of vermicomposting and bio-methanation plants are also possible with 1100 TPD.

To optimally use the biodegradable wastes combination of vermicomposting and bio-methanation plants are suitable techniques. Indian cities are classified as Class -I, Class-II, Class-III, etc. There are 415 Class -I cities in India. They have a population of 0.1 million to one million and generating municipal solid waste of 30-550 TPD.

This TPD MSW support in fuel oil production from plastic waste. To utilize biodegradable wastes optimally with 30 to 550 TPD using the combination of conventional compost (CC) and vermicompost (VC) and bio-methanation is the optimal technology option.

There is a possibility to construct a common or regional WTE plant for these cities after securing sufficient availability of RDF repeatedly from associating cities. The hill stations are also included with these cities, and local bodies should assure that technological options are appropriate and MSW is disposed of properly.

The peri-urban population even though they are villages is included in the urban population concerning the census. Their population is less than 0.1 Million, and they generate below 30 TPD of MSW. These MSW contain 30 %-65% of the biodegradable fraction of MSW. Using the combination of conventional compost (CC) and vermicompost (VC) and bio-methanation methods WTE is achievable. Furthermore, the most fitting technological choice for MSW management here is RDF.

The objective of the cities is to prepare and supply RDF after segregating dry waste properly. This RDF is provided to the WTE plants established in cities having a population higher than 1 million. The bio-methanation process generates biogas (10 TPD), and the biogas can be used for direct supply through pipelines or transforming to energy.

Furthermore, the biogas can be marketed commercially. The WTE plants currently in operation or under trial run are shown in Table 6 along with the various technologies utilized. There are 208 composting plants, 206 vermicomposting plants, 82 bio-methanation plant, and 45 RFD plants. As on 31.12.2018, the cumulative installed capacity of WTE is 138.30 MW.

4.3. Advantages and disadvantages of technologies for the waste to energy utilized in India

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 trans-esterification 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. Table 7 summarizes the advantages and disadvantages of the technologies [58].

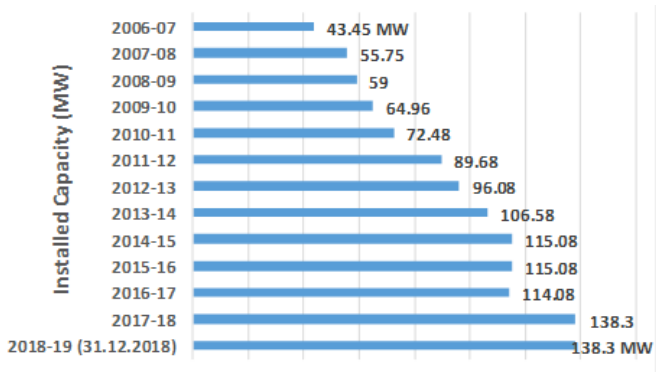


Fig.3.Waste to energy installed capacity from 2007 - 31.12.2018. [67]

Table 6 .WTE plants in India currently operational or under trial run [57]

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

Table 7 .WTE technologies in India –Advantages and disadvantages.

Technology	Advantages	Disadvantages
Anaerobic digestion / Biomethanation	A high volatile solids reduction ratio, Chemical Oxygen demand, and Biochemical Oxygen demand reduction, The end product is stable and odorless,The end product (liquid and a fibrous) has a high fertilizer value,The operation is smooth in the generation of gaseous fuel; the capital cost is low (small scale), total biogas and methane generation (net energy producing process), It does not require external power, unlike aerobic methods. Greenhouse gases emission to the environment is bypassed because all the gas produced are in an enclosed system. The visible pollution, fly menace, rodent, and lousy odor are not present in this technology. The plant needs less land area for modular construction	Aeration requires high power cost (capital intensive than landfilling and composting), Poor sludge dewaterability after digestion, sensitive to change in temperature and the material of the tank. If the digester is working under mesophilic temperatures, there will be less pathogenic organisms destructions than aerobic composting. No valuable material collected, pH and alkalinity would reduce during digestion (nitrification). If the biodegradable matter contained in the waste is less than the anaerobic /bio-methanation method is not fit for WTE. Odor nuisance is possible if the process carried out ineffectively. Segeration of waste to improve the efficiency of digestion.
Composting	To start sludge composting facility, lower investment of initial capital, slightly lower level of training to operate required than anaerobic digestion plants. It facilitates handling because typically by approximately 50% of the weight and volume of starting material is reduced — high carbon materials blended with high nitrogen materials to compost with carbon-nitrogen balance. It degrades volatile organic compounds and absorbs odors, binds heavy metals, avoids the formation of leachate and production of methane. Helps in soil ecosystem by suppressing soil-	Expensive to transport a bulky and weighty product.Nitrogen losses during the process of aerobic composting. Nutrient composition/value is low compared with chemical fertilizers. Potential of contamination is high. There is a need for sterilizing the composted material to remove infectious agents. Very good operating practice and detailed monitoring are required from the regulating bodies. A relatively large area is needed for windrow and aerated the static pile composting. Temperature affect the windrow and aerated the static pile composting and requires

	borne plant pathogens.	intensive maintenance. Odor nuisance is possible if the process carried out ineffectively same as bio-methanation.
Landfill gas recovery	The enhanced microbial action produces methane, cheap waste disposal option, local people will get a job, and it does not require skilled personnel., The gas from the landfill can be collected and utilized for heating purposes. If the waste needs to travel to the landfill site is short then the transport cost for the waste is minimized and reduce the amount of pollution created while transporting waste to the site. Decomposition of organic matter reduces the waste mass, and the site can be used longer. The cost to maintain the "landfill gas recovery" is less.	If the gas is exhausted, the generation site should be relocated. Bioreactor uses more water and landfills become less stable because of increased moisture. Initial capital cost is high for installing air/water circulating system. Bioreactor tends to produce rotten egg smell from the hydrogen sulfide gas produced. The electricity generated by fossil fuel is much more in volume than electricity produced by landfills. Local air pollution and global warming are possible from landfill sites because they give off dangerous gases. Local streams are polluted with poisons leaking through the ground from the landfill sites. Redevelopment is not possible in the location once it has been filled. Low paid employment from the jobs created in the local area. Noise pollution is caused by the big and noisy trucks delivering the waste to the site and the possibility of traffic congestion in that area. There are chances for an explosion due to methane gas.
Incineration	Incineration destroys contaminant medical wastes and other life-threatening waste. Power generated by incineration plants is in high demand. Incineration can reduce waste by 95% and reduce the quantity of land needed. The heat from incinerators is used for warming homes and workplace. Incineration pollutes the environment less than landfills, and they use filters to trap dangerous gases and toxins. Incinerators work within the requisite pollution boundaries and also provide much control over odor and noise. Methane gas is not produced and therefore making incineration safer. They destroy germs and chemicals because they are operating at a very high temperature — most fit for massive calorific value waste. Build within the cities and transportation cost is reduced. Operate in any type of weather conditions. Ash produced can be used for many applications such as construction and shipping of ash is cheaper.	Installation is an expensive process. Constructing the infrastructure and operating costs are very high. Incineration requires trained personnel for operation. Regular maintenance required. Smoke (acid gases), heavy metals, carcinogen dioxin, nitrogen oxide, and particulates during the burning process pollute the environment and also produce cancer-forming chemical. Incineration does not encourage waste reduction and recycling. Ash waste harm the well being of society and the environment. It is not fit for wastes which are aqueous, low calorific value and substantial moisture content.
Pyrolysis / Gasification	Lower temperature method than incineration. Feed rates are high (five tons per hour). Syngas (carbon monoxide, hydrogen, and methane) or recovery products are generated by controlling the degree of pyrolytic reaction — immediate reduction in volume and weight. Less space is required. Waste stabilization and energy recovery are higher. The gas has 4 to 10 MJ/Nm3 net calorific value. Ash (residue of noncombustible materials) has low carbon level.	Higher capital cost, skilled labor is required. Fume incineration is necessary to destroy outcomes of incomplete combustion and hazardous organic components. Excessive moisture in waste is a problem in net energy recovery. Pyrolysis oil with high viscosity is also a big problem during burning and transportation.
Refuse-derived fuel (RDF)	Refuse-derived fuel has excellent calorific value (homogenous fuel with higher content of heat) and does not have much bi-product that pollute the environment. In the existing coal-fired boiler RDF can be burned as a supplement fuel, and the RDF waste processing system offers increased material recovery potential. The preliminary liberation step separation of municipal waste to biodegradable results (removing inert, non-combustible) in negligible operational	Pre-processing (preliminary liberation, size screening, shredding) to recover the fuel fraction cost is higher. Maintenance cost of processing equipment (energy intensive) price is high. During the shredding process (crushing and cutting) the possibility of explosions is higher, and high-speed shredders must be designed to withstand explosions..

	difficulties in the combustor. RDF requires lower excess air and therefore operates at higher efficiency. Handling is easier since non-combustibles have been previously extracted.RDF follows "size screening" which results in a more efficient combustion process. Ash handling is easy, and fuel characteristics result in an RDF boiler system is less expensive and offset the cost of processing equipment. Health risks, emissions are less.	

5. The Potential for Energy Recovery

The country has a potential for WTE from municipal solid waste is 2.554 GW and 1.683 GW from urban and industrial waste.

5.1. The industrial and municipal waste and their estimated potential for energy recovery

Solid waste is collected and treated in SWM. Residential, industrial and commercial areas create solid wastes such as waste developed during construction work, biowastes from farming, horticulture cultivation lands, deforestation, forest-related activities, hazardous wastes from battery sources, paints, tints, chemical solvents, bleaching agents and pesticides used in the agriculture lands. These solid waste should be managed effectively through WTE to obtain energy because solid wastes are also responsible for creating unsanitary conditions in the environment and develop pollutions [59,60,61,62]. Table 8, presents the state-wise WTE potential of the country. The estimated potential of WTE is 2.554 GW as per MNRE annual report 2016-17. As of 31.12.2018, the cumulative installed capacity of WTE is 0.1383 GW. It shows that only 5.4 % was achieved until the date. The cumulative of renewable energy in India as of 31.12.2018 was 74.08166 GW, and the WTE have contributed 0.18% only. Wind energy contributed 47.43%, solar 34.03%, biomass power/cogeneration 12.25%, small hydro 6.098%.Biomass power/cogeneration and WTE are classified as biopower category in India [63].

Maharashtra produces more waste, and the possibility of WTE is high. The state is second populated in the country with 9% of the total population next to Uttar Pradesh with 16%. Maharashtra stands first in a large number of industries such as textile, food processing, cement, chemical, steel industries next to Punjab, Tamilnadu and West Bengal. The WTE potential of this state is 0.287 GW followed by Uttar Pradesh with 0.176 GW and Tamilnadu with 0.148 GW.

Table 9 shows the state-wise potential of energy from urban and industrial wastes. There is a potential of about 1700 MW (1.7 GW) from urban waste as per MNRE estimation. Out of this 1700 MW of potential, 1500 MW (1.5 GW) is from MSW and 225 MW (0.225 GW) from sewage and about 1300 MW from industrial waste. Indian Renewable Energy Development Agency (IREDA) estimates show that the country has so far realized only about 2% of its WTE potential [64, 65].

5.2. Energy recovery from MSW- State wise estimated potential

The solid waste generated from the towns and cities in the country has present potential to create the power of approximately 500 MW (0.5 GW), which can be enhanced to 1075 MW (1.075 GW) by 2031 and further to 2780 MW (2.780 GW) by 2050. The State-wise potential for power generation from MSW is shown in Table 10 [66]. MSW is growing attention in recent years. The MSW management includes the collection, transportation, handling and conversion to power through biological and thermal routes [67].

6. Waste to Energy installed Capacity

In 2007, the installed capacity of WTE was 43.45 MW, In April 2017 it was 75.80 MW which included urban 3.50 MW, Industrial 72.30 MW. The cumulative achievement reached 138.30 MW as on 31.12.2018 which is shown in Fig.3 [68,69]. Fig.4 shows the comparison of various renewable installed capacity in India as of 31.12.2018. The country has installed capacity over 74 GW of renewable capacity as of June 2018. By 2022, India is aiming the installation of 175GW of renewable energy capacity (60 GW from wind power, 100 GW from solar power, 5 GW from small hydropower). The objective given to bio-power is 10 GW which includes biomass power (Biomass & gasification, bagasse cogeneration, and WTE). An ambitious objective of 175 GW by 2022 will need a five-fold increase in the WTE sector.

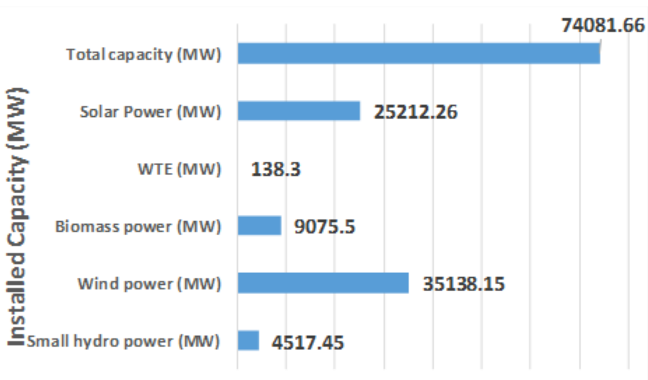


Fig.4. Renewable cumulative installed capacity as of 30.12.2018 [29]

Table 8. State-wise Waste to Energy Potential in India: MNRE Annual Report 2016-17 [61].

No.	State/Union Territory	Potential (GW)
1	Andhra Pradesh	0.123
2	Assam	0.008
3	Bihar	0.073
4	Chandigarh	0.024
5	Delhi	0.131
6	Gujarat	0.112
7	Haryana	0.024
8	Himachal Pradesh	0.002
9	Jharkhand	0.010
10	Kerala	0.036
11	Madhya Pradesh	0.078
12	Maharashtra	0.287
13	Manipur	0.002
14	Meghalaya	0.002
15	Mizoram	0.002
16	Orissa	0.022
17	Pondicherry	0.003
18	Punjab	0.045
19	Rajasthan	0.062
20	Tamil Nadu	0.151
21	Tripura	0.002
22	Uttar Pradesh	0.176
23	Uttarakhand	0.005
24	West Bengal	0.148
25	Others	1.022
	Total	**2.554**

Table 9. Energy Recovery Potential from Urban and Industrial Wastes: MNRE 2011[62]

No.	State/Union Territory	From Liquid Wastes* (GW)	From Solid Wastes (GW)	Total (GW)
1	Andhra Pradesh	0.016	0.107	0.123
2	Assam	0.002	0.006	0.008
3	Bihar	0.006	0.067	0.073
4	Chandigarh	0.001	0.005	0.006
5	Chhattisgarh	0.002	0.022	0.024
6	Delhi	0.02	0.111	0.131
7	Gujarat	0.014	0.098	0.112
8	Haryana	0.006	0.018	0.024
9	Himachal Pradesh	0.0005	0.001	0.0015
10	Jharkhand	0.002	0.008	0.01
11	Karnataka	0.026	0.125	0.151
12	Kerala	0.004	0.032	0.036
13	Madhya Pradesh	0.01	0.068	0.078
14	Maharashtra	0.037	0.25	0.287
15	Manipur	0.0005	0.0015	0.002
16	Meghalaya	0.0005	0.0015	0.002
17	Mizoram	0.0005	0.001	0.0015
18	Orissa	0.003	0.019	0.022
19	Pondicherry	0.0005	0.002	0.0025
20	Punjab	0.006	0.039	0.045
21	Rajasthan	0.009	0.053	0.062
22	Tamil Nadu	0.014	0.137	0.151
23	Tripura	0.0005	0.001	0.0015
24	Uttar Pradesh	0.022	0.154	0.176
25	Uttaranchal	0.001	0.004	0.005
26	West Bengal	0.022	0.126	0.148
	Total	0.226	1.457	1.683

Table 10. The State-wise potential for power generation from MSW: MNRE 2014. [64]

No.	State/Union Territory	Power Equivalent (GW)
1	Andaman & Nicobar	0.001
2	Andhra Pradesh	0.043
3	Arunachal Pradesh	0.001
4	Assam	0.002
5	Bihar	0.006
6	Chandigarh	0.001
7	Chhattisgarh	0.007
8	Delhi	0.028
9	Goa	0.001
10	Gujarat	0.031

11	Haryana	0.013
12	Himachal Pradesh	0.006
13	Jammu & Kashmir	0.007
14	Jharkhand	0.017
15	Karnataka	0.035
16	Kerala	0.006
17	Madhya Pradesh	0.019
18	Maharashtra	0.062
19	Manipur	0.001
20	Meghalaya	0.001
21	Mizoram	0.002
22	Nagaland	0.001
23	Orissa	0.009
24	Pondicherry	0.002
25	Punjab	0.015
26	Rajasthan	0.019
27	Sikkim	0
28	Tamil Nadu	0.053
29	Tripura	0.001
30	Uttar Pradesh	0.072
31	Uttaranchal	0.005
32	West Bengal	0.032
	Total	0.500

6.1. State-wise waste to energy installed capacity (MW)

Table 11 shows the State-wise waste to energy installed capacity (MW) as of 2016-17. Andhra Pradesh has the highest Installed capacity of 58.16 MW, followed by Delhi and Maharashtra [70,71]. From 2012 to 2018, WTE capacity increased from 89.68 MW to 138.30 MW.

7. Electricity Generation from Waste to Energy Sources

Table 12 shows the generation of electricity (MU) from WTE sources. With the help of suitable technology, India can generate electricity every month using WTE. Table 13 shows the comparison of Electricity generation from various renewable energy sources for the year 2018 (April 2018-Dec 2018). It is observed that wind generate more electricity than other renewable sources followed by solar. Between April 2018-Dec 2018 ,wind-generated 53124.09 MU cumulative electricity , solar generated 45478.9 MU, biomass 2035.81 MU, bagasse 7451.18 MU, SHP 7409.38 MU[72].The cumulative for WTE in 2018 (April –Dec) was 318.58 MU, and 2017 (April –Dec) was 264.81 MU.

8. Government Support and Policies to Promote Waste to Energy Projects

The MNRE is encouraging, supporting and developing WTE to obtain a sufficient volume of decentralized energy for the people. Suitable technology for WTE options is made through R&D.MNRE is promoting setting up of WTE projects through two schemes namely. (1) National programme on energy recovery from urban & Industrial Wastes. (2) United National Development Programme (UNDP)/Global Environment-friendly (GEF) supporting the project on the development of high rate bio-methanation processes as a system of decreasing GHG Emission [73]. Central Financial Assistance (CFA) provided by the Ministry which is given in Fig.5. The MNRE provides CFA for starting up of WTE plants which are utilizing industrial MSW, urban, and agricultural waste to produce energy. The Ministry of Housing and Urban Affairs (MHUA) has the “Swachh Bharat Mission” under it also provides around 35% of support to complete the WTE projects based on the solid waste processing guidelines.

8.1. Power projects based on industrial wastes

Based on the installed capacity the cost of the capital allowance/subsidy is determined and provided 50 million per project or 20% of the project value. If there arose an occurrence of progressing project endorsed by the MNRE under the current interest subsidy amount, the promoters would be provided an alternative to getting the undisbursed CFA cost balanced against the advance (loan) as single-time assistance from the MNRE after the project is commissioned efficiently. The MNRE is practicing proper discount factor for the funds that are released to IREDA / Other FIs / Banks to avoid any extra outgo of funds from the MNRE. The aggregate CFA sum will be proportional to the original sanctioned interest subsidy cost. The projects previously agreed to ‘in principle’ by the Ministry, but could not be approved so far, would be given on merit are shown in Table 14 [74].

8.2. Power projects based on urban wastes

The main objectives of the energy restoration from urban wastes is to support in setting up projects and building favorable atmosphere for bio-methanation projects which utilize cow /sheep/birds dung, gas from sewage, residues after slaughtering animals, scraps from vegetable/flower markets, wastes from agricultural lands. Budgetary assistance to be granted to encourage the project under this Programme is outlined in the subsequent sections [75].

8.2.1. Production of energy from sewage treatment plants

Biogas is generated by sewage treatment plants (STP) as WTE, and the ministry is providing financial support to this projects and is limited to 0.272639 million USD/MW (INR 20 million/project). The project assistance includes the cost of the diesel engine and electric generator, removal of hydrogen sulfide and other associated facilities to run the plant.

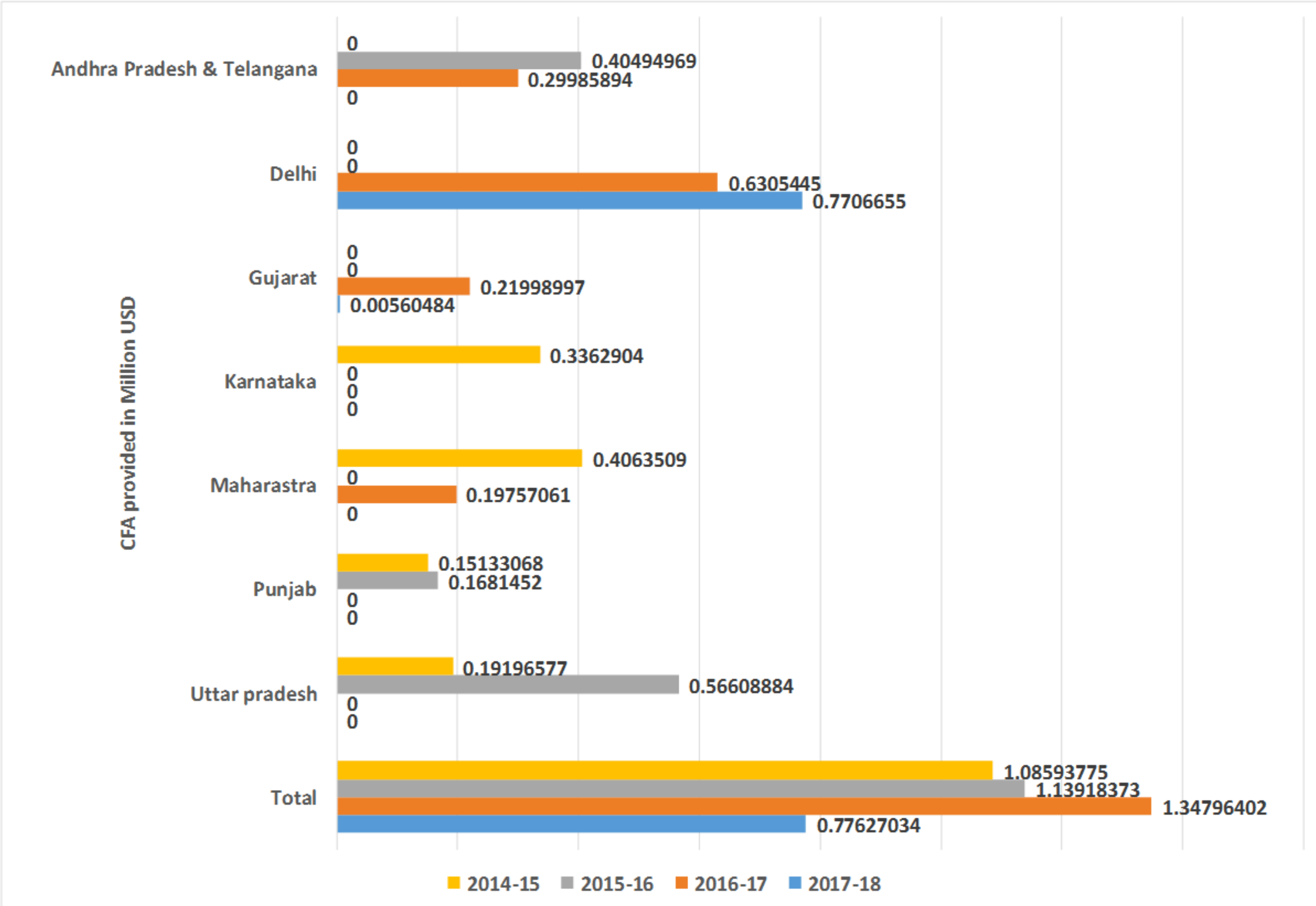


Fig.5. Stat State/UTs wise details of Central Financial Assistance provided by the MNRE during the last three years and the current year-Lok Sabha Unstarred question No.3159 (31.08.2017).

Table 11. State-wise waste to energy installed capacity (MW) [68] [69]

No.	State/Union Territory	Installed capacity (MW)					
		2011-12	2012-13	2014-14	2014-15	2015-16	2016-17
1	Andhra Pradesh	43.16	43.16	50.66	58.16	58.16	58.16
2	Delhi	16	16	16	16.00	16.00	16.00
3	Karnataka	1.00	1.00	1.00	1.00	1.00	1.00
4	Madhya Pradesh	3.90	3.90	3.90	3.90	3.90	3.90
5	Maharashtra	5.72	9.72	12.72	12.72	12.72	12.72
6	Punjab	9.25	9.25	9.25	10.25	10.25	9.25
7	Tamil Nadu	5.65	8.05	8.05	8.05	8.05	8.05
8	Uttar Pradesh	5.00	5.00	5.00	5.00	5.00	5.00
	Total	89.68	96.08	106.58	115.08	115.08	114.08

Table 12.The generation of electricity (MU) from waste to energy sources [70]

MU	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019
April	35.220	22.450	15.750	34.610	38.640
May	32.770	28.280	16.350	27.270	39.030
June	37.440	23.480	15.590	27.900	36.720
July	37.110	23.640	18.000	31.290	30.650
August	31.250	22.350	11.830	28.610	32.530
September	20.250	19.410	14.360	24.320	32.16
October	22.270	20.140	13.640	26.520	34.87
November	22.090	18.640	16.070	32.060	37.29
December	32.140	19.600	16.070	32.240	36.69
January	18.330	21.430	16.330	29.330	
February	29.750	25.840	23.31	31.190	
March	29.300	23.280	36.020	33.120	

Table 13. Electricity generation using WTE (April 2018- Dec 2018) [30]

MU	18-Apr	18-May	18-Jun	18-Jul	18-Aug	18-Sep	18-Oct	18-Nov	18-Dec	Cumulative 2018	Cumulative 2017
Wind	3322.74	4441.09	8336.94	11365.27	11771.66	6093.34	2822.78	2181.03	2789.24	53124.09	45478.9
Solar	3178.88	3322.72	3012.37	2553.02	2635.79	3209.96	3452.61	3140.99	3078.3	27584.65	17334.68
Biomass	255.43	253.59	285.86	225.1	185.61	177.17	206.31	199.72	247.01	2035.81	2598.46
Bagasse	1263.94	728.01	393.48	319.56	218.28	231.36	426.26	1558.8	2311.49	7451.18	5991.84
Small	384.14	472.04	761.27	1193.6	1530.91	1001.29	872.37	678.16	515.62	7409.38	6592.22
WTE	38.64	39.03	36.72	30.65	32.53	32.16	34.87	37.29	36.69	318.58	264.81

Table 14. The Capital Subsidy to the Promoters [74]

Capital Subsidy to the Promoters	Wastes / Processes /Technologies	Capital Subsidy
Biogas from Industrial Waste	Biomethanation of difficult industrial Wastes and low energy density (Slaughterhouse, dairy, bagasse wash, tannery, Sugar(liquid), the pharmaceutical industry, textile industry liquid, paper industry liquid	INR 10 Million / MWeq. (12000 Cu.M. biogas per day. [0.1359 Million USD]
	Biomethanation of different industrial Wastes	INR 5 Million / MWeq. (12000 Cu.M. biogas per day) .[0.0679 Million USD]
Generation of power from Biogas	Turbine configuration of steam and boiler	INR 8 Million/MW.[0.1086 Million USD]
	Configuration of biogas engine/turbine	INR 10 Million/MW .[0.1359 Million USD]
Generation of Power from Solid Industrial Waste	Turbine configuration of boiler and steam	INR 8 Million/MW.[0.1086 Million USD]

8.2.2. Production of energy from urban wastes

Ministry provides financial support to projects based on bio-methanation technology utilizing wastes of the vegetable markets, the dung of the cattle, scraps after slaughtering cows, sheep, and hens. The upper ceiling of the assistance is 50% of these project cost or maximum USD 0.40896 Million/MW (30 Million INR/MW). It is expected to show 250kW project capacity concerning energy generation from cattle dung. Similarly, biogas (12000 cu.m /day) as an end product of the plant, the financial support is limited to 0.1359 Million USD/MWeq (INR 10 Million.MWeq].

8.2.3. Production of energy from agricultural wastes/ residues

Peri-urban and urban area agriculture waste is utilized by the pants to generate energy are considered in the scheme. The plants can be constructed in the area of waste availability if needed. The expected capacity is 20 MW, and the financial support of 81791 Million USD (60 Million INR) is given after the evaluation of the project.

8.3. Municipal Waste Based Power Projects

Monetary assistance (capital subsidy) to be granted by MNRE under the municipal waste based power projects programme for setting up five pilot projects on recovery of energy from MSW. Financial support at a flat rate of INR 2.00 crore per MW [20 Million INR/MW, 0.272639 million USD/MW], subject to a maximum of 20% of project value and INR 10.00 crore per project [100 Million INR per project, 1.3632 Million USD per project], whichever is less. Fiscal support to be granted for projects chosen through a transparent, competitive system [76].

8.4 Guidelines for Development of Projects

The expert committee recommends the project development outline, and the Honorable Supreme court of India decided concerning the recommendation on May 15, 2007. Key recommendations of the Expert Committee regarding the development of MSW based WTE projects are: **1.**The project development should include close coordination between promotors and municipal corporations. The financial assessment and endorsement of the project should be adequately addressed. The concerns such as project development including characterization of wastes, technology selection, sizing of projects, management model and operational matters, and project design should be incorporated.**2.** The growth of population and urbanization have increased the difficulties in treating and disposing of the municipal wastes (solid and liquid). As given in the MSW Rules, 2000, an integrated approach to waste processing and treatment will be required.

Accordingly, instead of concentrating on specific technologies, it would be advisable to take an integrated approach to the management and treatment of MSW, which would require the deployment of more than one technology in tandem.**3**. Based on the local conditions and the quality of waste to be treated will decide the choice of technology for the SWM. According to the MSW rules, it is essential to segregate solid waste at source, and the selection of technology will be relatively more natural to have high performance and success of the chosen technology.**4**. The Committee has also suggested regarding projects based on bio-methanation of MSW. It is stated that the waste segregation plant/process can segregate waste suitable for bio-methanation. Projects based on bio-methanation of MSW should be carried out only on separated/uniform waste unless it is demonstrated that in Indian conditions.

9. Current Status of Waste to Energy Projects in India

Ministry of Urban Development (MoUD) has got 53 WTE project proposals from 22 states of the country with the potential to produce 405.3 MW(0.4053 GW) of electricity under Swachh Bharat Mission (SBM) in 2016 which are currently under several stages of development or tendering which is shown in Table 15 [77]. In 2016, WTE plants operational/under trial run in the country with the total capacity of 66.5 MW, Maharashtra with 3 MW, and Delhi with 52 MW and Madhya Pradesh with 11.5 MW. There are only eight functional WTE thermal plants with a total capacity of 94.1 MW currently are operational in India. The provincial allocation is as follows - Maharashtra with 2 WTE plants, New Delhi with 3, Madhya Pradesh with 1 WTE, and Himachal Pradesh with 1 WTE. The companies running these plants are Rochem, ORSPL, JITF, IL&FS, Ramky, Essel, and Elephant Energy Private Ltd.

The subsequent five years roadmap need to have constant and strict monitoring of the air quality in the WTE plants which are functional. The administration must be institutionalized and should not depend on high court/supreme court directives. Apart from intending at the fast utilization of accumulated mounds of waste, the following five years need to be prepared to finish the incomplete projects of around 398 MW in the pipeline or delayed or stranded for a variety of causes such as legal difficulties, need of monetary assistance from banks, non-availability of land, etc.

The basket may also add WTE plants which have been started but are held up at various stages. This is achievable given the evidence that the modern tariff policy provides a preferential tariff to energy from solid waste and this tariff has remained a powerful attraction for the public, private power partnerships. Fast completion of these 50 projects which have already been initiated will benefit many cities and towns, such as Tirupati, Guntur, Tadapalligudam,Vizianagaram,Rajahmundry,Machilipatanam, , Kadapa, Ongole, Nellore, Anantapur, Karnul, Visakhapatnam, Surat, Karnal, Patna, Bandhmadi, Srinagar, Sonepat, Faridabad, Bengaluru (7 plants) Kochi, Bhopal, Gwalior, Nagpur, Rewa, Indore, Nashik, Kalyan Domvili, Imphal, Kidwai Nagar, Bhubaneswar, Paramkudi, Cuttack, Amritsar, Rameswaram, Pallavapuram, Tambaram, Coimbatore, Jaipur, Jodhpur, Venkatmangalam, Perambulur, 18 ULBs in Telangana, Greater Hyderabad Municipal Corporation, Kanpur, Agra, Rampur, Lucknow, Meerut, and Roorkee (Cluster of 18 Urban Local Bodies.)

This will guarantee utilization of 30000 MTs of solid waste per day for energy production of 398 MW which is equal to three times, i.e., 1194 MW of solar (1:3). The items are presented in Table 16 [78]. The MNRE has financed 180 WTE plants based on MSW, urban & industrial waste for generation of power, biogas, and bioCNG. These plants are operating well reaching the desired purpose of employing agricultural waste, urban waste, industrial waste and MSW for producing energy, generating biogas and BioCNG. The State-wise features of these WTE plants with installed capacity and quantity of plants set up, as on 15.12.2017, are provided in Table 17 [79,80,81,82,83,84,85].

Table 15. Waste to Energy thermal Plants under various stages of Construction or Tendering-2016 [77].

No.	State/Union Territory	Number of plants	Total proposed capacity (GW)
1	Andhra Pradesh	11	0.085
2	Assam	1	0.005
3	Bihar	1	0.012
4	Chhattisgarh	2	0.01
5	Delhi	1	0.0016
6	Gujarat	3	0.0305
7	Haryana	3	0.0185
8	Himachal Pradesh	1	0.0017
9	Jammu & Kashmir	1	0.0065
10	Jharkhand	2	0.023
11	Karnataka	2	0.02
12	Kerala	1	0.01
13	Madhya Pradesh	5	0.032
14	Maharashtra	3	0.0285
15	Manipur	1	0.001
16	Odisha	1	0.0115
17	Tamil Nadu	1	0.008
18	Telangana	1	0.011
19	Uttar Pradesh	5	0.025
20	West Bengal	1	0.0225
	Total	53	0.4053

Table 16. Record of 50 WTE under Tender/Bidding/Construction/Agreement Stage to be floated-2018 [77]

S.No	States in India	City/Town	Input Capacity (MTPD)	Input Capacity (MTPA)	Production Capacity (GW)	Status(under construction/Tendering/ DPR)	Date of Commissioning
1	Andhra Pradesh	Guntur	1202	438730	0.15	Under Construction	October -2018
2	Andhra Pradesh	Tirupati	374	136510	0.06	Land acquisition in progress	October -2018
3	Andhra Pradesh	Vizianagaram	203	74095	0.04	Under Construction	December-2018

4	Andhra Pradesh	Tadapalligudam	342	124830	0.05	Under Construction	December-2018
5	Andhra Pradesh	Mach alipatnam	196	71540	0.04	Land acquisition in progress	December-2018
6	Andhra Pradesh	Rajahmundry		0	-	Under tendering	-
7	Andhra Pradesh	Ongole		0	-	Under tendering	-
8	Andhra Pradesh	Kadappa	317	115705	0.05	Under Construction	December-2018
9	Andhra Pradesh	Anantapur	283	103295	0.04	Under Construction	December-2018
10	Andhra Pradesh	Nell re	296	108040	0.04	Under Construction	Jun-2019
11	Andhra Pradesh	Karnul	316	115340	0.01	Under Construction	September-2018
12	Andhra Pradesh	Vishakapatnam	942	343830	0.15	Under Construction	October-2018
13	Bihar	Patna	1000	365000	0.1	Agreement signed	March-2018
14	Chhattisgarh	-	500	182500	0.05	-	-
15	Chhattisgarh	-	500	182500	0.05	-	
16	Gujarat	Surat	1000	365000	0.115	Under Construction	November-2017
17	Haryana	Karnal	350	127750	0.035		
18	Haryana	Sonepat	500	182500	0.05	-	-
19	Haryana	Bandhmadi	1000	365000	0.1	-	-
20	Haryana	Faridabad	1000	365000	0.1		
21	Jammu & Kashmir	Srinagar	450	164250	0.065	Under Tendering	December-2019
22	Karnataka	Bengaluru (7 plants)	2000	730000	0.2	Under Tendering	
23	Kerala	Kochi	500	182500	0.1	Tender Finalized	December-2018
24	Madhya Pradesh	Bhopal	1000	365000	0.23	Tender Awarded	May-2019
25	Madhya Pradesh	Rewa	600	219000	0.06	Tender Awarded	August-2019
26	Madhya Pradesh	Indore	1100	401500	0.2	Tender Awarded	December-2018
27	Madhya Pradesh	Gwalior	600	219000	0.15	Tender Awarded	January-2020
28	Maharashtra	Nagpur	700	255500	0.115	Tender awarded	July-2019
29	Maharashtra	Nashik	25	9125	0.0025	Under Construction	
30	Maharashtra	Kalyan Domvili	600	219000	0	Under Construction	
31	Manipur	Imphal	100	36500	0.02	Under Construction	July-2017
32	New Delhi	Kidwai Nagar	70	25550	0.016	Under Construction	Pending
33	Odisha	Bhubaneswar & Cuttack Odisha	700	255500	0.115	Tender Finalized	January-2017
34	Punjab	Amritsar	700	255500	0.116	Under Construction	December-2017
35	Rajasthan	Jaipur	1000	365000	0.15	EC awaited, PPA Submitted to RERC for tariff finalization	December-2019
36	Rajasthan	Jodhpur	200	73000	0.03	EC awaited, PPA Submitted to RERC for tariff finalization	December-2019
37	Tamil Nadu	Rameshwaram	-	0	0.0001	Machinery Erection	-

						Under Progress	
38	Tamil Nadu	Coimbatore		0	0.0002	Completed	-
39	Tamil Nadu	Paramkudi	0	0	0	Completed	-
40	Tamil Nadu	Pallavapuram & Tambaram ,Venkatamangalam Project	300	109500	0.04	Under Construction	March-2018
41	Tamil Nadu	Perambulur		0	0	Completed	
42	Telangana	The cluster of 18 ULBs (M/ S Shalivahana MS WM Green Energy Ltd)	1000	365000	0.12	Dormant (Issue with PPA and Tipping Fee)	August-2017
43	Telangana	Cluster of 16 ULB (M/s Hemasri Power Projects Ltd.)	1000	365000	0.126	Under Construction	August-2017
44	Telangana	Greater Hyderabad Municipal Corporation (RD F Power Projects Ltd.)	1000	365000	0.11	Plant Ready Presently in Trail Run	August-2017
45	Uttar Pradesh	Kanpur	1000	365000	0.15		
46	Uttar Pradesh	Agra	500	182500	0.05	Tender Finalized	January-2019
47	Uttar Pradesh	Rampur	500	182500	0.08	Tender Finalized	December-2017
48	Uttar Pradesh	Lucknow	1000	365000	0.15		March-2019
49	Uttar Pradesh	Meerut	1000	365000	0.1	Tender Finalized	
50	Uttarakhand	Roorkee (Cluster of 18 ULBs)	2000	730000	0.25	Under Construction	December-2017

Table 17. State-wise features of WTE plants set up with installed capacity and number of plants, as on 15.12.2017 [77].

	States/Union Territories	MSW based power plants GW (Number of Plants)	Agricultural, Urban & Industrial Effluent/Waste based Waste to Energy plants			
			Grid Power	Off-grid Power	Biogas	BioCNG
			GW (Number of Plants)	GW (Number of Plants)	GW (Number of Plants)	GW (Number of Plants)
1	Andhra Pradesh	-	0.02316 (4)	0.01766 (12)	74.640 (6)	-
2	Bihar	-	-	-	12.000 (1)	-
3	Chhattisgarh	-	-	0.00033 (1)	-	-
4	Delhi	0.05200 (3)	-	-	-	-
5	Gujarat	-	-	0.01128 (10)	24.840(4)	12.538 (2)
6	Haryana	-	-	0.0040 (2)	-	2.050 (2)
7	Himachal Pradesh	0.00175 (1)	-	-	12.000 (1)	-
8	Karnataka	-	0.00100 (1)	0.0048 (3)	58.080 (3)	-
9	Kerala	-	-	-	2.760 (1)	-

10	Madhya Pradesh	0.00900 (1)	0.0039 (2)	-	5.640 (3)	1.200 (1)
11	Maharashtra	0.00300 (1)	0.00959 (3)	0.01463 (10)	73.080 (8)	19.533 (3)
12	Punjab	-	0.00925 (2)	0.00417 (3)	33.720 (5)	1.847 (1)
13	Rajasthan	-	-	0.0030 (1)	-	4.000 (2)
14	Tamil Nadu	-	0.0064 (3)	0.00405 (3)	142.920 (27)	-
15	Telangana	-	0.0185 (3)	0.0010 (1)	30.000 (4)	-
16	Uttar Pradesh	-	-	0.04463 (22)	46.200 (4)	-
17	Uttarakhand	-	-	0.00189(2)	67.200(5)	5.460(1)
18	West Bengal	-	-	-	14.040(2)	-
	Total	0.06575 (6)	0.0718 (18)	0.11144 (70)	597.120 (74)	46.628 (12)

Table 18. Business opportunities in the WTE sector [90]

Primary collection	Collecting the reusable metals and reusable plastics and can be sold to the regional markets Processing RDF (biodegradable material, plastics) which can be sold to WTE biomass plants. Construction wastes can be utilized to build bricks and tiles, and this can be transported to the brick factory.
Wet organic wastes Separation	Composting organic matter for the fertilizer companies Selling the power generated from WTE biomass plants to the grid.
Secondary storage after collecting	Involving in maintaining the location for waste transport, participating in the screening of waste materials which includes recycling, WTE and disposing of in the landfills.
Wastes recycling	Involving in the business of waste material transfer and recycling Selling the recycled metals and plastics to the WTE plants.
Logistics and Transportation	Transporting the solid waste from the source to WTE plant or carrying the waste from WTE plant to landfills. Making automobiles parts or complete automobiles for the WTE plants or the contractors based on the requirements
MSW to energy recovery	Involving in manufacturing machinery and equipment for the WTE plants based on the technology requirements. Involving in the installation of the WTE projects. Involving in power generation and selling the power to people or the grid. Producing organic feedstocks and treating organic feedstocks from MSW Apply for financial support from the government for following the accepted emission standards.
Waste management at the dump site	Planning for secured landfills and designing them with appropriate improvements. Creating secured landfills in the deserted landscapes.
Funding	Debt and equity funding.

Table 19. List of companies benefiting from the WTE sector [90].

Primary collection and dry waste separation	Different informal sector members, rag pickers, recycling firms
The primary collection, processing the wet waste after separation	Various informal sector members, farmers, firms manufacturing fertilizers, agriculture market companies
Controlling the resources that are collected, stored and transported to the WTE plant or destination	Engineering companies, procurement companies, and construction companies (EPC), vehicle manufacturing companies, private automobile service providers, agencies dealing with transports, workers employed as part-time.
Secondary collection from the stored primary collection to the WTE plant or destination	Engineering companies, procurement companies, and construction companies (EPC), building contracting companies, shop owners selling junks of MSW, Services provider from logistics companies.
Waste material recycling	Engineering companies, procurement companies, and construction companies (EPC), operators involving in material recovery and providing facilities, units doing cottage business, companies providing environmental engineering services, shop owners selling junk.
MSW to energy	Fabricating companies, technicians for WTE plant services, Dealers of MSW, producers of MSW, RDF providers.
Landfill waste management processes	Engineering companies, procurement companies, and construction companies (EPC), companies involved in civil infrastructure developments.

10. Business and employment opportunities

With increasing public awareness about sanitation, and with growing pressure on the government and urban local bodies to regulate waste more efficiently, the Indian WTE sector is poised to expand at an accelerated pace in the years to come, starting up attractive avenues for investment for businesses. WTE business and job opportunities have been steadily increasing from year to year in the last decade. Technological advancements in materials, materials handling and consumer practice patterns remain to influence waste-handling systems, building capabilities and innovation within the industry.

With this constant increase in demand, this means the WTE market is abundant of opening for potential business and employment. Human actions have grown extra influential in environmental degradation over the past few decades with wastes [86]. There are 377 million total urban population in the country, 62 million tons of yearly generation of MSW and 1240 hectares of landfill needed per year if the waste remains untreated. Municipal officials are executing the rules of the MSW (management and handling 2000) to maintain the waste management processes effectively through well build infrastructure. This rule was established by the Ministry of Environment & Forests (MoEF) [87].

10.1. Waste Collection and Transport

Waste collection, storage, and transport are necessary elements of any SWM system and can be significant hurdles in cities. Waste collection is the duty of the municipal corporations in the country, and waste-bins are generally provided for inert waste and biodegradable waste [88,89,90]. Mixed inert waste and biodegradable waste is usually dumped, with open burning a general method. Changes to waste collection and transport infrastructure in the country will generate employment, promote public health and improve tourism [91]. Local bodies spend approximately INR.500–1000 per ton [6.82 -13.64 USD] on SWM with 20% of the expense spent on transport and 70% on collection. Business opportunities are present in each segment of the WTE value chain. The various business possibilities that exist along the MSW to energy value chain has been presented in Table 18. Recycling companies, agriculture farmers, rag pickers, construction companies, locomotive companies, logistic companies, etc. are benefited from the WTE sector. Table 19 outlines the various companies that are profited from the WTE sector [92].

10.2. Supply Chain Management

Fig.6 presents supply chain management in the country. There is a scope of transforming the informal sector into a positive contributor to waste management. Waste transported from the source to the transfer stations where after partial separation, the similar feed material is transferred to the respective treatment facility. Commercial industries based upon the legislation on quantity and quality of waste transfer the waste generated to the transfer point. There is also contracts with the company to discard the industrial scraps.

10.3. Reuse and recycling of waste by the informal sector in the country

The informal sector must be integrated into formal SWM systems because the informal sector has a significant role in the country [93]. The informal sector is defined by labor-intensive, small-scale, often unregulated and unregistered low-technology manufacturing or provision of services and materials [94]. Waste pickers get household, or industrial/commercial waste and several hundreds of thousands of waste pickers in the country depend on garbage for their income, despite the associated social and health problems. Pickers extract potential value from dumpsites, waste bins, trucks, waterways, and streets. Some of them work in recycling plants maintained by waste picker associations or cooperatives. Waste picking is usually the only source of revenue for families, giving a livelihood for significant numbers of urban poor and usable materials to other companies. Waste pickers in India gather organic waste for composting and generation of biogas. Waste pickers also make a notable contribution to keeping cities clean.

A current study of six Indian cities observed that waste pickers collected nearly 20% of waste, with 80000 citizens committed to recycling about three million tons. It is determined that each ton of recyclable material collected preserved the ULB around INR 24500 per annum [334.1063 USD per annum] and avoided the emission of 721 Kg CO_2 per annum [95].

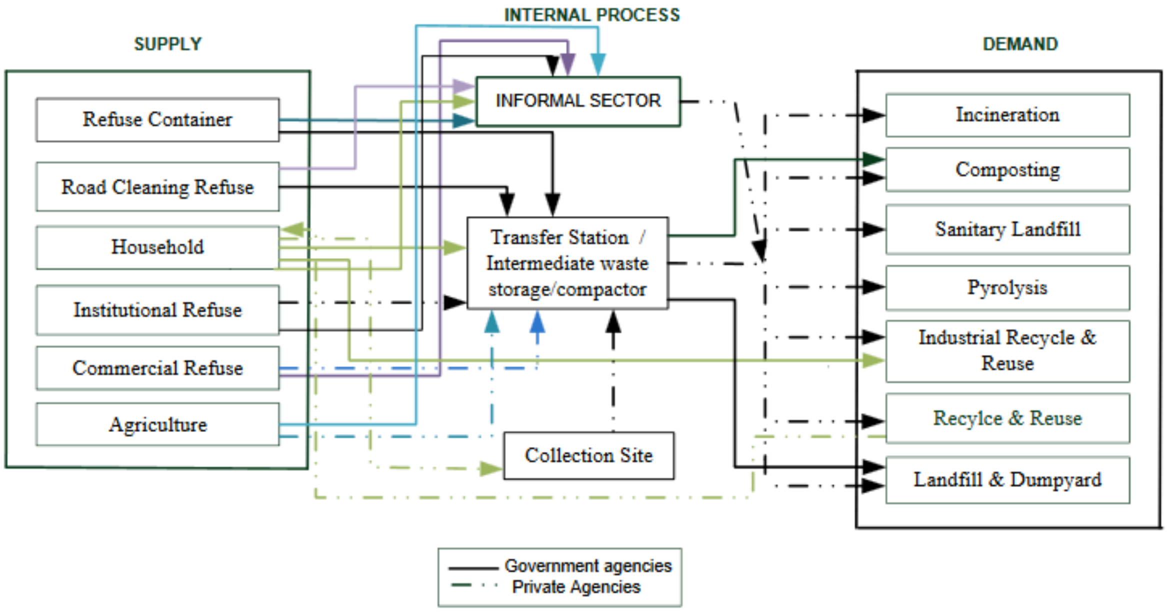


Fig.6. Supply chain management in India [90]

11. Environmental Aspects and Impacts of a Waste to Energy

MSW is an unavoidable by-product of the society and needs to be handled in an environmentally sound and protecting health manner. Disposing of waste through landfills raises health hazards 30-fold, compared with using WTE, which produces several types of energy, example: steam, electricity, by combusting MSW. The advantages [96,97] of WTE are the majority of waste that would usually go into landfill sites can be re-used. 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 [98].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 technology is the controlled ignition of waste with the heat recovery to generate steam that in turn produces energy by steam turbines. MSW after pretreatment is supplied to the boiler of a suitable alternative wherein high-pressure steam is utilized to create electricity by a steam turbine. Pyrolysis is widely employed in the petrochemical industry and can be implemented to municipal waste processing where organic waste is converted into combustible residues and gas. Gasification is another option which usually operates at a higher-temperature than pyrolysis in a limited quantity of air. While both pyrolysis and gasification are available technologies to handle municipal waste, commercial applications of either technology have been limited. Incineration-based techniques have been a subject of intense debate in the environmental, social and political circles.

11.1 Incineration and Environmental Issues

The incineration of waste is a standout amongst the most popular techniques of thermal processing of waste that can be utilized to a full circle of various types of waste [99]. The modern incineration plants which are operating essentially designed for treating municipal solid waste, industrial waste, biomedical waste and hazardous waste. The typical waste-incineration facility is shown in Fig.7 which includes the following operations: 1. Waste storage and feed preparation.2.Combustion in a furnace, producing hot gases and a bottom ash residue for disposal.3.Gas temperature reduction, often including heat recovery via steam production.4. Treatment of the cooled gas to eliminate air pollutants, and disposal of residuals from this treatment method.5. Through a stack and induced-draft fan, the treated gas is dispersed to the atmosphere. There are several variations to the incineration method, but these unit operations are common to most plants. Proper design and maintenance of these "front-end" plant operations are needed for various reasons: 1.While the plant is running, the potential for operator exposure to dangerous materials is the highest in this part of the facility. Operators can be exposed to hazardous vapors and dust if there is no proper engineered and administrative controls, including individual protecting equipment.2. This part of the plant is the most critical potential fire hazard and the most significant potential source of vapor emissions and fugitive dust to the atmosphere.3. The furnace combustion performance may be reduced if there is no proper waste preparation and feeding. There are numerous laws and guidelines for the design and operation of waste storage, handling, and feeding systems [100].

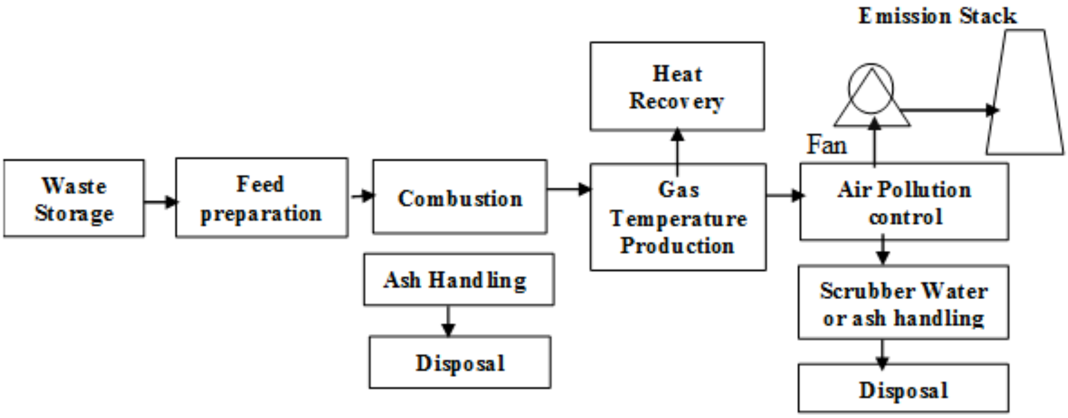


Fig.7. Typical waste-incineration facility schematic [97].

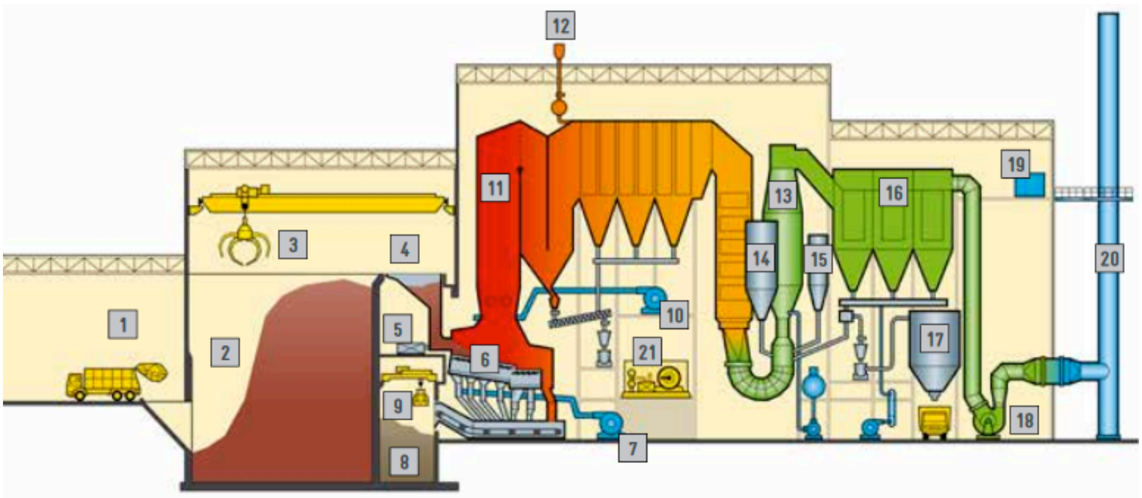


Fig. 8. Components of an MSW incineration plant with flue gas cleaning [99].

Table 20. Components of an MSW incineration plant with flue gas cleaning [90].

Delivery of waste	Process of Incineration	Cleaning of flue gas	Recovery of energy
1. Vehicles are scaled and enter the vast garage area. 2. Dump the gathered waste into the holding pit called the bunker. 3. A substantial indoor crane continuously supplies waste into boilers. 4. Garbage feeding channel.	5. Automatic Ram feed system 6. Grate incinerator 7. Combustion of fuel (primary fan) 8. Bunker for bottom ash 9. Crane for bottom ash 10.Combustion of fuel (secondary fan) 11. Incineration steam boiler 12. The safety valve of the boiler	13. Reactor to treat flue gas 14. Injection of hydrated lime to lower the emission of HF and HF. 15. Injection of activated carbon to control toxins 16. Filter bags 17. Fly ash separation from flue gas 18. Induced draft fan to take hot flue gases from the furnace through dust collector. 19.Monitoring System for emissions (CEMS) 20. Incinerators stack (Chimney)	21. Energy recovered through the Steam turbine or steam generator

Fig.8 shows the components of an MSW incineration plant and the details of various parts are shown in Table 20 [101] with flue gas cleaning. The environmental effects of Incineration are discussed in the subsequent sections.

11.1.1. Combustion

The organic and inorganic molecules are cut down with the well-designed incinerator hot flame in the combustion process which emits carbon dioxide, nitrous oxide, oxides of nitrogen, oxides of sulfur, organic carbon, and ammonia and metal vapors [102]. During normal operation of incineration, methane is not emitted except exceptional and avoidable cases. Carbon dioxide constitutes the primary pollutant in the environment. If there is incomplete combustion carbon monoxide is emitted. Oxygen reacts with carbon to form CO, Hydrogen with oxygen forms H_2O, chlorine reacts with hydrogen to form HCL; hydrogen reacts with fluorine to form hydrofluoric acid [103,104]. Oxidation of sulfur are the main reasons for acid rains. Adding lime into the incineration process lower the oxidation of sulfur. The unoxidized sulfur becomes ash or flue gas [105]. Very poisonous metals such as mercury, lead, copper, cadmium are mixed with the fuels, ash, and flue gas [106]. Very toxic persistent organic carbons (POC) are also present in the process of incineration to contaminate the environment.

11.1.2. Ash and Toxins

The incineration reactor consists of furnace and stack which send out fly ash and bottom ash respectively. The fly ash is nearly 9%-10% of the total volume of MSW and 19%-36% by weight of the total MSW [107,108]. The ash from the end of stack consists of dangerous compounds which are hazardous to the environment. The toxins are present throughout the stack parts including scrubber water, filters, and pipes and also with the air plumes leaving the stack. The only safe method available is air emission control using filters after the energy recovery is gained from the waste. It is not continuously feasible to avoid the emission, and the emission control process itself is very costly, and sometimes the toxins are stuck in the filters and produce dangerous wastes. The trapped toxins in the filter and waste need to be disposed of safely without contaminating the environment requires specific landfills. Heat exchangers in the incineration produce more toxins and sometimes if the flue gases again go into the heat exchangers forming reverse of energy recovery leads to spreading ashes everywhere in the atmosphere. This produced ash is spreading even affect the food chain of the environment and public health.

11.1.3 Human Health Concerns

The WTE helps in decreasing waste to produce heat and energy. The incineration filters and scrubbers are employed for trapping pollutants and also avoid generation of methane and other greenhouse gas from the decaying waste in the landfills. WTE also helps in protecting groundwater from contamination. Despite being an attractive technological alternative for managing waste effectively, WTE has disadvantages. Harmful pollutants and toxins emitted show the negative influence on human health as it contaminates the air, water, and the land. The dioxin and furans produced by incineration process affect the people who are living nearby because these dioxins are incredibly cancerous. The residents living nearby the incineration plants breathe the emitted air from furnace even though the plant is following various environmental standards and procedures based on air emission control. The agriculture lands are severely contaminated by these pollutants and residents eating the vegetables and other products from the agriculture lands. The lake, river, and pools are incredibly affected due to the continuous emission of toxic hazardous pollutants which affect the creatures living in the water and also affect the people eating fish and drinking water from the lake or river. The adverse effect of pollutants affect the various systems of the human body. United Nations Environment Program (UNEP) has announced that incinerators are the main reasons for toxins in the atmosphere. Many researchers pointed out that high exposure to the 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD) which is carried in the herbicide mixture agent orange is the principal toxin adding to critical cancer complications [109,110].

11.2 Biomedical Waste to Energy

The Indian health sector is using medical devices of various top medical device companies in the world such as Medtronic Inc, Johnson & Johnson, Siemens, Philips, Depuy Synthes, etc. Every day the country is producing more than 500 tons of biomedical waste. Inadequate biomedical waste management and inappropriate disposal cause a lot of risks in human health and environmental problems such as air, water, and land pollution. The biomedical wastes are infectious, toxic radioactive and hazardous. This waste contains blood and microorganisms which spreads infections in the surroundings. The biomedical waste also contains plastic and combustion of these wastes produces toxic elements such as dioxins and furans. Poisonous elements and compounds of mercury are also discharged during the incineration process which poisons and pollutes the environment which affects the people in the surroundings. To secure sustainable health care, there is an urgent requirement to attend to suitable waste management techniques which incorporate conventional collection, separation, storage, packaging, labeling, transportation and choosing proper WTE technologies or proper disposal techniques [111]. The biomedical waste management and handling rules of India were released in 2016. Ministry of Health (MoH) in India imposed severe laws, rules, and regulations that should be followed by any health care sector concerning biomedical waste. The ministry created awareness among the medical personnel concerning the negative impact imposed on the environment and human health and providing training towards proper waste handling and disposal methods. The Directorate General of health services (DGHS), Ministry of health & family welfare (MOHFW), Central pollution control board (CPCB) and Ministry of Environment, Forest & Climate (MEFC) are working towards sustainable health care and provided guidelines for biomedical waste and choosing proper WTE. This guideline covers various possibilities of disposing of biomedical wastes such as plastics through WTE which can then be used for laying roads and in the production of diesel [112]. National Accreditation Board for Hospitals and Healthcare Providers (NABH) also covers the biomedical standards in its accreditation process to the health sectors.

Biomedical wastes are color-coded as yellow (all wastes are needed to be burned), red (wastes that can be recycled), blue (glass wastes) and white (sharps). Some of the methods practiced include incineration, landfilling, autoclaving, microwaving and plasma pyrolysis. The disposal of liquid wastes such as human body fluids are into the sewage and drains. Even though proper disinfection practices are followed before discarding these wastes, the useful bacteria in the drainage are affected. Solid and organic wastes which are not possible to be recycled or reused are treated using incineration methods [113,114,115]. Even though incineration kills pathogens and lessens the volume and weight of the biomedical waste, it produces waste ash which will affect the environment and ozone layer with its organic composites and inorganic salts which emit a foul smell and create a breeding place for insects. If the incineration process is incomplete or if the adequate temperature is not maintained the complete eradication of pathogens is not achieved as incineration requires excess airflow and low-temperature incinerators produce furans and toxins. The ash from incineration methods is disposed of using landfills. These landfills may contaminate the groundwater, resulting in skin diseases and other undesired health issues in the surrounding population.

Furthermore, landfilling produces harmful gases, CO_2 and methane and create severe destructive effects on the environment. The biomedical solid wastes such as cellulose polymer dressings, blood bags made from PVC, rubber gloves made from polyurethane and silicon, rubber, glass, and catheters made from polyethylene and polymethyl methacrylate are disposed of using plasma pyrolysis method. This method uses high temperature and flux of ultraviolet radiation which destroys the pathogens and energy is recovered from the produced gases. This method is also used for disposal of biomedical wastes such as plastics, cotton, tissues and pathological wastes. Very low dioxins and furans are released in this method with effective eradication of pathogens. In this method, biomedical wastes are pyrolyzed into hydrocarbons, H_2 and CO. For example, polyethylene with water and heat are pyrolyzed to form CH_4, CO, and H_2. Exothermic reactions take place during the combustion of CO and H_2. For example $CO+0.5O_2=CO2$ and $H_2+0.5O_2=H_2O$. These reactions will release energy as light and heat. Recently Plasma gasification is considered as sustainable management of medical wastes. It uses plasma torches which converts biomedical wastes into a syngas (synthesis gas) which is composed of H_2 and CO which can be turned into liquid fuels, electricity, and heat [116]. Another recent method includes anaerobic digestion of biomedical waste resulting in the production of biogas. Biogas consists of CH_4, CO_2, H_2O, and other gases in the oxygen-free anaerobic digester. The biogas is combusted to generate heat and electricity [117]. Nowadays biological fuel cells are used to convert biomedical waste such as blood and saliva to energy using biocatalyst in which the organic matter is converted into electricity.

Few suggestions to the government to overcome the excess generation of biomedical waste and appropriate treatment to generate electricity is provided. Firstly, the government should frame standardized definitions for biomedical waste segregation, transportation, disposal methods and choosing suitable WTE technology. Effective rules should be implemented to stop the health care sector dumping wastes illegally and stop environmental pollutions. The rules should be sturdy and robust with regulatory bodies. Secondly, the government can give incentivizes to the health care sector for not producing more biomedical waste and following the biomedical waste management rules and regulations. The government can provide grants in case WTE is followed in the health care sector, the energy produced is used for their hospital and reduce the requirement of electricity from the concerned state electricity board or the central electricity board. Finally, governments should have a partnership with industries producing biomedical products to use in hospital and can recycle the biomedical waste through R&D of the industry and WTE technologies. The government can support the industry if they are manufacturing medical equipment which will produce very low mercury and dioxins during the incineration process to generate energy from biomedical waste from concerned hospitals.

12. Building the Environment and Waste Management Legislation

The following needs to be followed to achieve the environmental law structure, emission limitation policies, intentions of WTE and MSW.

1. Tendering Policy: The government decision-makers should consider the global recognized effluents, emission and safety criteria concerning WTE technology during tendering processes and make sure that they select the product of the company which can produce a decidedly less hazardous byproduct of various WTE techniques. The government should monitor the emissions and effluents, occupational safety and health.

2. Environmental policy and law: Even though the WTE is the potential solution to overcome increasing volume of waste which generates energy, public health, safety, ecology should not be undermined. Environmental protection should be a priority. The government should allow WTE plants only if it follows the environmental protection laws, emission compliance standards which need to be measured now and then.

3. WTE operators/administrator guarantee: They are required to guarantee that the installation of the WTE plant will not produce the harmful effect on the residents living near the plant, rivers, ponds, lakes, agriculture lands and forests.

4. Protection and environmental measures: WTE plant should follow the air quality standards, emission thresholds, and safety conditions. The government should strictly monitor whether these rules are followed and make sure that WTE plants follow the universally accepted standards and practices else there are possibilities of risk to the public health and the environment. Occupational health should be the highest priority for the employees working in WTE plants.

13. Barriers in Waste to Energy in India

The following are the crucial hurdles and barriers faced by the country in developing WTE.

1. Energy generation from waste and WTE technology is still a new idea to develop WTE technology unlike wind and solar renewable energy technologies.

2. The equipment needed for WTE technologies is imported from abroad. For example, projects based on bio-methanation technology are very costly, and the materials are imported.

3. MSW (Management and handling) rules 2000, is not favorable to the MCs and ULBs.

4. Most of the time segregated waste is not available to the WTE plants.

5. There is not enough financial assistance provided to the MC/ULB in waste management and implementing WTE technology.

6. Favorable policy guidelines are lacking concerning land allocation to build WTE plants and supply of waste from waste generation sources.

7. Appropriate techniques and methods are not followed concerning acquiring waste, segregation, treatment, choosing WTE technology.

8. Poor responsibility for waste management and WTE technology is prevailing in the country

9. Municipality corporations do not have enough funds to have efficient waste management and implement WTE technology or plants.

10. Environmental impacts and public health concerns are not considered during the selection of techniques

11. Public involvement and participation are very poor concerning waste management and WTE technology because citizens are not conscious of the benefits of this technology and low motivation by the government to the community.

12. There is a deficit of training to the employees, and less number of professionals in waste management technology is available.

13. Most of the times WTE plants receive poor quality of wastes in which generation of energy is not possible, and the result is unsatisfactory.

14. The capital cost to build the WTE plant is very high and also the operation and maintenance cost is also considerably high-priced.

15. There are no proper strategic plans to develop WTE in the country.

16. The government funding administrative structure is also becoming barriers because loans or funds are nor delivered in time and the bank are hesitating or slow sanctioning loans to WTE plants.

17. There is no proper coordination among the central, state governments and MCs.

18. Few unsuccessful WTE projects are creating poor motivation among the investors and the general public. For example, within a year of commissioning 6 MW, MSW to biogas project plant was shut down because of poor waste quality.

19. There is no dedicated WTE research center for R&D.

20. Getting long-term PPAs from the state electricity board (SEB) is very tough.

21. The supply chain is weak.

22. The "Swachh Bharat Mission" concentrating on solar power affecting the WTE and biomass technologies.

22. An inadequate flexible financial model is missing to bring down the cost of the technology.

23. Municipal corporations are not cooperating with the WTE plant's administrators and officials.

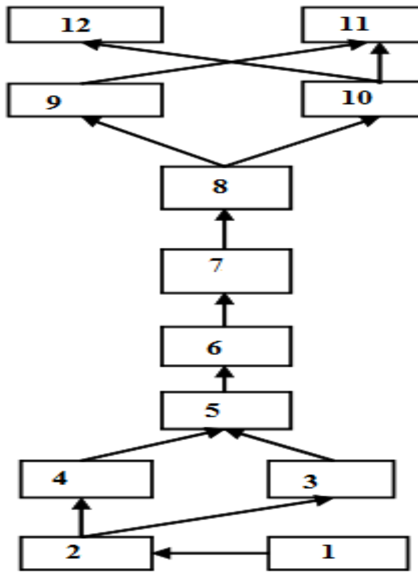
24. The political garbage mafia in India is bringing obstacles starting from waste collection to WTE plants.

25. Most informal recycling community are affected by WTE regulations who depend on waste for their livelihood. [118].

Most of the SWM researches focused on scientific analysis only. Fig.9 shows the managerial characteristics of SWM and the reasons for failures. It shows the principal obstacles and interrelationships. If the listed inadequacy are considered during waste management and WTE technologies, the possibilities of success will be considerably high [119].

14. Policies Require to be Modified, Evolved or Adapted to Encourage this Sector

Current society produces a large measure of waste daily of which a considerable part is dangerous and can't be disposed of utilizing regular treatment. Prominent projects are a nightmare and more inclined to failure. The government should endeavor to make great strategies (policies) for establishing decentralized solid waste disposal plants. No “one solution” or technology meets all needs. Some suitable equipment is utilizing clean technology to assure the removal of garbage without contamination of the atmosphere and considering emission standard, ought to be invented. It should be equipment suitable at any locality producing wastes. A few increases to the equipment on a later date may be made intending WTE and even by using a small Stirling engine utilizing heat generated by waste burning. An effective waste management strategy requires an integrated method where recycling and WTE are given due significance in the policies of the government. The government should endeavor to set up a dedicated WTE research Center to build up a lost-cost and low-technology solution to harness clean energy from millions of tons of waste produced in the country. The government is devising several WTE projects in various cities in the coming years which may support in handling the waste situation to some extent. However, government policies ought to be inclined towards including waste management, whereby the informal recycling society is not taken of its livelihood because of WTE projects. The government should further try to make favorable policies for the foundation of decentralized WTE plants as huge projects are a logistical nightmare and more inclined to failure than small-to-medium scale projects.



1. Incomplete law and missing implementation 2. The plan for waste management is Inadequate 3. Inadequate resources monitoring 4. Improper choice of location for the plant 5. The monetary pressure on ULBs 6. Very less number of trained workers and insufficient training for the workers. 7. No evidence of benchmarking to evaluate the effectiveness of services	8. Not selecting the WTE technology appropriately 9. Weak contract administration 10. Inadequate public awareness regarding WTE technologies. 11. Workers disputes with the WTE plant administrators 12. The participation of the community/residents decidedly less

Fig.9. Twelve barriers identified from earlier studies and validated through experts' opinion-Planning commission of India [117]

15. Recommendation for Course of Action in the WTE Sector

The decision-makers can recognize the following recommendations/guidelines during the investigation, selection, and approval of the WTE technologies.

1. Waste stream can be assessed appropriately for energy generation, reuse and recycle. A particular portion of the waste is more suitable for WTE and can be treated with proper technology.

2. WTE technology should follow internationally accepted standards and agreements.

3. Considering the global experiences in tendering, monitoring and strengthening mechanisms.

4. Waste volumes, waste quality, waste availability, waste characteristics, and technology choices related information, should be readily available for proper waste management using WTE. Mid-term to the long-term growth of waste volumes investigations need to be prepared.

5. Municipal Corporation plays a vital role in collaboration with WTE plants, and they should be financially strong and supported by the concerned government to collect waste and supply to the WTE plant regularly without any delay or issues.

6. Arrangements and collaboration should be apparent and active between the municipality and the WTE plants to transport and dispose of residues of the plant such as ash etc. effectively.

7. The technically and financially strong nature of waste management practices should be planned before implementing WTE projects for waste management.

8. To show excellent performance and maintenance of the WTE plants' investment and banking support is required and it is imperative to have security for sustainable advancement of the WTE plants.

9. Robust investment plans, strategic plans, and reasonable forecasts are significant to run WTE plants effectively, and revenue through power sale can be recognized to face the capital cost, operation, and maintenance cost.

10. For the effective running of the plant qualified and trained staff should be employed and given frequent training related to technical and managerial responsibilities. For some duties, outsourcing can be done to minimize the load of the existing employees.

11. Proper planning of backup and emergency capacity should be the higher priority. Legal security for the WTE plant should be ensured, and the vision of the WTE plant should be transparency, trust to provide clean energy to the people through WTE technologies which are environmentally and public health friendly.

12. Instead of importing all equipment from abroad consider using the domestic equipment for WTE before planning to introduce material from elsewhere. Try to combine with local equipment with few imported equipment to save capital investments. Sometimes it will be hard to maintain the domestic equipment and is equal to about one-third to one-half the cost of imported technologies.

13. Improve waste separation and use appropriate waste for WTE. Most of the time moisture content in the waste lowers the efficiency of the technology and produce dioxins.

14. The people should be given awareness related to their ethical responsibility in classifying /separating waste through environmental education.

15. Promotion through marketing methods to the companies and citizens to encourage waste separation, recycling, and reuse.

16. WTE market can be standardized and enhance the current plant. To manage, develop, monitor, examine, and inspect the operation of the plant-specific administrative agencies can be established. Legal liability concerning pollutant discharge contamination outflows needs to be considered. Severe penalties can be imposed on the plants which are not following acceptable standards and creating problems to the environmental and public health.

17. Public support is more critical to run the WTE plant. The general public can actively participate and supervise the WTE plants. The inhabitants living near the plant should be given job preferences and offer them a suitable position. Environmental security of the plant should be clearly explained to the general public. The plant should be provided with clear information related to the functioning and activities of the plant and make them realize that the plant is safe. The government should publish details of the plant, clear guidelines, policies, procedures, and services of the plant. The government can give heat and power to their residents to inspire the residents near WTE plants. In case the residents are affected by the plant outcomes the government should provide money and must provide full medical expenses to the affected one.

18. Hold twice per year a “Swatch Bharat” global investors meet (waste to gold global investors summit) just in the territory of waste to vitality in India to guarantee accessibility of land, labor, and funds in the WTE sector. This meet will assist in building awareness, get worldwide consideration, and set up innovative policies in place.

19. Strategy to reconstruct the sector should be based on building an eco-system of market efficiency as is the case for the “solar mission”. The mission can distinguish lands for landfilling on a scientific base following global standards. If government land is unavailable, private property can be picked on such terms that farmers considerably profit from the project. Waste processing companies could provide job and investment shares to the ex-land owners so that they continue working associates in the running of the project. Rag pickers can be trained through an apprentice project so that they become agents of technology development all along the value chain of 5R of Zero waste (refuse, reduce, reuse (+repair), recycle, rot). The rag pickers can even be qualified to be agents of change.

20. Solar Energy Corporation of India (SECI) can be renamed as Renewable Energy Corporation of India (RECI) and extend its charge to take over waste management on an outsourced basis based on need aggregate. As a public sector undertaking (PSU), SECI can become a sound rehabilitation and education/training center of the rag pickers by appropriately connecting their training with the Ministry of Skill Development and Entrepreneurship (MSDE).SECI can also examine the growing e-waste sector in the country, which as of now reuses under 2 % of the e-waste. India has no institutional method to recycle, reuse, dispose of electronic waste (e-waste) and is the fifth biggest generator of e-waste globally. Subsequently, there is a sovereign duty to set up an organization in place to intelligently and responsibly manage the large waste sector, both existing and rising. SECI can plan nationwide, remembering that WTE is one of the alternatives for SWM. In most Indian cities and towns, MSW has enormous moisture content and lower paper and plastic content. This prompts to a low calorific amount, performing the MSW inappropriate for current direct combustion routes, dissimilar to other developed countries with substantial plastic/paper content and low moisture content. Consequently, Indian MSW is more suited to biological processes (organic procedures) such as anaerobic/aerobic digestion, pyrolysis or gasification. In any case, these procedures can work competently if the waste is segregated correctly and the organic matter utilized for energy recovery. In some rare cases, plasma gasification can be utilized which is considerably overpriced. Henceforth, effective WTE policy requires a vital strategy/policy for segregation and recycling. SECI can aggregate usage of computer modeling and simulation devices that assist in evaluating the economic viability and tariff for MSW projects, considering the physical, social and chemical properties of Indian waste produced as MSW.

21. Linkages between waste characteristics (high calorific value and low moisture content) and plant technology. The economics of these forthcoming plants must be measured carefully and accurately. Given that, waste quantities are moving upward, and their well-being and environmental consequences are significant, the plants can't stop abruptly without political and health effects. Subsequently, technology selection will be crucial for policymakers.

22. The policymakers need to understand the long-term result of the WTE policy in their long-term waste management policies/strategies.

23. A WTE policy cannot deny the source of living to millions of rag pickers without general rehabilitation plans in case complete waste moves to energy generation without significant scope for recycling and reuse. Thus, it needs to concentrate on making them more proficient, educated/trained and employable with higher salaries and considerably better social advantages which are effortlessly possible with greater focus and plan.

24. “Zero waste municipalities” with tools for local R&D on waste and information distribution centers. The policymakers, with the guidance of Association of Municipalities and Development Authorities (AMDA), need to design for a network of zero waste municipalities with the cooperation of United Nations Centre for Regional Development (UNCRD).

25. India's Zero Waste Association should be a member of the International Solid Waste Association (ISWA) and zero waste auditing as a business/market policy/strategy.

26. The country has enormous scope to run big chains of zero packaging shops, especially the modernized malls to spread out the use of zero packaging to a growing middle class who are environmentally much conscious.

27. The policy must be connected to the sustainable development goals (SDGs), and it ought to be guaranteed that the general population at the lower rungs know the significant relationships among the practice, policies and projected intentions. Both policymakers and people ought to realize that waste is not to be wasted anymore, and its appropriate management with the point of zero waste and almost zero landfilling ought to be a preference issue and preference item. This policy can be from the joined investigation of Global waste management outlook, United Nations Environment Programme (UNEP) and the International Solid Waste Association (ISWA).

28. Pricing tool for Bio-CNG and model document for purchase/sale agreement with oil and gas marketing companies. This will assist in promoting a market for WTE, which is very nascent at this step.

29. Rationalization of financial support for various projects on WTE.

16. Conclusion

The cost of energy from conventional energy sources is becoming very high and harnessing power from waste is becoming more important nowadays. The waste management techniques are cost-effective, environmentally friendly and accepted socially. Waste management is showing more advantages such as reducing greenhouse gases, reducing wastes, income from energy sale, reuse of waste materials. The WTE technology is controlled and maintained by the MNRE of India which has a multilevel governance system which builds strategies, policies, plans, outlining and implementing. The government is providing financial support to waste management through WTE. It supports in establishing novel and advanced technologies. Private investment is giving strong support to implement WTE technology and plant. There are few regulatory barriers such as the economics of scale, learning economics and unstabilized supply chains and structure of the market which stop the commercialization of the innovative and profitable technologies. Sometimes current infrastructure is not allowing to include advanced technologies in WTE plant. Most of the time the WTE sector is providing enormous business potential with high income for the companies and people who are directly or indirectly involved in the WTE processes. At the same time, the WTE have few undesirable effects on the environment which pollute soil and water with chemicals included in ash during landfill and smoke from the plant. To have an excellent future for the WTE sector R&D for the sector should be considered and supported by the government. There should be research collaboration between the plant and the research institutions. Research centers can be constructed within the WTE plant campus. Researchers and scientists should be allowed to investigate and do research in the WTE plant. The investigation should include efficient waste management techniques and technology following environmental impact studies.

Furthermore, there is no undergraduate course offered in any university in India related to WTE technologies. The Ministry of education along with MNRE should frame syllabus, curriculum and start an undergraduate course on WTE and provide the scholarship for the students to carry out their studies. The research scholars to obtain Ph.D. degree research can work on WTE and advancements in WTE technologies. The partnership and MoU between the WTE sector, companies, and educational institutions should be healthy to have steady growth in this sector. There should be an efficient method to explore WTE potential. The government should encourage and provide business opportunities to the companies and people in this sector. The collaboration between local waste management officials and the different ministries responsible for framing policies for waste management, energy, and environment should be healthy and robust. Top-down plans should be communicated effectively. Higher intellectual waste treatment using advanced technology and disposal is needed to have environment-friendly and to reach the goal which is still far from achieved, and several steps need to be taken to develop the WTE sector.

17. Abbreviations

WTE	Waste to Energy
MT	Metric Tons
MSW	Municipal Solid Waste
GHG	Green House Gas
MNRE	Ministry of New and Renewable Energy
STP	Sewage Treatment Plants
VGF	Viability Gap Funding
SWM	Solid Waste Management
ULB	Urban Local Bodies
MC	Municipal Corporations
EPC	Engineering, Procurement, and Construction
NGO	Non-governmental organizations
CFA	Central Financial Assistance
MHUA	Ministry of Housing and Urban Affairs
IREDA	Indian Renewable Energy Development Agency
TPD	Tons Per Day
RDF	Refuse-Derived Fuel
UNDP	United National Development Programme
GEF	Global Environment-friendly

CFA	Central Financial Assistance
ILFS	Infrastructure Leasing & Financial Services Limited
IREDA	The Indian Renewable Energy Development Agency
HUDCO	The Housing & Urban Development Corporation Limited of India.
TCO	Technical Consultancy Organization
CER	Certified Emission Reductions
MOEF	The Ministry of Environment & Forests
POP	Persistent Organic Pollutants
UNEP	United Nations Environment Programme
PPA	Power Purchase Agreements
SEC	State Electricity Board
UNCRD	United Nations Centre for Regional Development
AMDA	Association of Municipalities and Development Authorities
ISWA	The International Solid Waste Association
SDG	The sustainable development goals
UNEP	United Nations Environment Programme
MBT	Mechanical Biological Treatment
MOH	Ministry of Health
DGHS	Directorate General of Health Services
MOHFW	Ministry of Health & Family Welfare
CPCB	Central Pollution Control Board
MSDE	Ministry of Skill Development and Entrepreneurship
CEA	Central Electricity Authority of India

Acknowledgments

The authors gratefully acknowledge the support provided by Government Primary Health Centre, Mulanur (Dharapuram, Tirupur, Tamil Nadu)-India, Chinmaya Mission Hospital (CMH), Bengaluru-India, the Research Consultancy Institute (RCI) of Effat University-Saudi Arabia, and the KACST Technology Innovation Centre for Solid State Lighting at KAUST-Saudi Arabia.

References

[1] Molla Shahadat Hossain Lipu, Md. Shazib Uddin, Muhammad Ahad Rahman Miah, "A Feasibility Study of Solar-Wind-Diesel Hybrid System in Rural and Remote Areas of Bangladesh", International journal of Renewable energy research, vol.3, No.4, pp.892-900, 2013.

[2] S. Traore Alfred, "Biogas production from Calotropis procera: a latex plant fund in West Africa", Bioresource Technology, vol.41, pp. 105-109,1992.

[3] A.Y. Mahamat, R. Gourdon, P. Leger, P. Vermande, "Methane recovery by anaerobic digestion of cellulosic materials available in Sahel", Biological Wastes, vol.30, pp.181-197, 1989.

[4] S.K. Jain, G.S. Gujral, N.K. Jha, P. Vasudevan, "Production of biogas from Azolla pinnata R. Br. and Lemna minor L.: Effect of heavy metal contamination", Bioresource Technology, vol.41,pp.273-277,1992.

[5] S.A. Abbasi, P.C. Nipaney, M.B. Panholzer, "Biogas production from the aquatic weed pistia (Pistia stratiotes)", Bioresource Technology, vol.37, pp.211-214,1991.

[6] B. Nirmala, D. Somayaji, S. Khanna, "Biomethanation of banana peel and pineapple waste", Bioresource Technology, vol.58, pp.73-76,1996

[7] K. Devianai, R. Kasturi Bai, "Batch biomethanation of banana trash and coir pith, short communication", Bioresource Technology, vol.52, pp.93-94,1995.

[8] J.J. Lay, "Biohydrogen generation by mesophilic anaerobic fermentation of microcrystalline cellulose", Biotechnology and Bioengineering, vol.7, pp. 281-287,2001.

[9] **9**.H.S. Shin, J.H. Youn, S.H. Kim, "Hydrogen production from food waste in anaerobic mesophilic and thermophilic acidogenesis", International Journal of Hydrogen Energy, vol.29, pp. 1355-1363,2004.

[10] S. Tanisho, Y. Ishiwata, "Continuous hydrogen production from molasses by fermentation using urethane foam as a support of flocks", International Journal of Hydrogen Energy,vol.19, pp.807-812,1994

[11] H. Yu, Z. Zhu, W. Hu, H. Zhang, "Hydrogen production from rice winery wastewater in an up-flow anaerobic reactor by mixed anaerobic cultures", International Journal of Hydrogen Energy,vol. 27, pp. 1359-1365, 2002.

[12] H. Yokoi, Saitsu As, H. Uchida, J. Hirose, S. Hayashi, Y. Takasaki, "Microbial hydrogen production sweet potato starch residue", Journal of Bioscience and Bioengineering, vol.91, pp.58-63,2001.

[13] H. Yokoi, R. Maki, J. Hirose, S. Hayashi, "Microbial production of hydrogen from starch manufacturing wastes", Biomass and Bioenergy,vol. 22, pp.389-395,2002.

[14] S.V. Ginkel, S.E. Oh, B.E. Logan, "Biohydrogen production from food processing and domestic wastewaters", International Journal of Hydrogen Energy, vol.30 , pp. 1535-1542,2005.

[15] M. Okamoto, T. Miyahara, O. Mizuno, T. Noike, "Biological hydrogen potential of materials characteristic of the organic fraction of municipal solid

wastes", Water Science and Technology, vol.41 , pp.25-32,2000.

[16] J.J. Lay, Y.J. Lee, T. Noike, "Feasibility of biological hydrogen production from organic fraction of municipal solid waste", Water Research, vol.33, pp. 2579-2586,1999.

[17] V.C. Kalia, S.R. Jain, A. Kumar, A.P. Joshi, "Fermentation of biowaste to H2 by Bacillus licheniformis World Journal of Microbiology and Biotechnology", vol.10, pp.224-227,1993.

[18] J.J. Lay, "Biohydrogen generation by mesophilic anaerobic fermentation of microcrystalline cellulose", Biotechnology and Bioengineering, vol.74, pp.280-287,2001.

[19] M. R. Al Mamun, and S. Torii ," Anaerobic co-digestion of cafeteria, vegetable and fruit wastes for biogas production", Renewable Energy Research and Application (ICRERA), 2014 International Conference, DOI: 10.1109/ICRERA.2014.7016412, 19-22 Oct. 2014.

[20] Asokan Pappu ,Mohini Saxena ,Shyam R.Asolekar, "Solid wastes generation in India and their recycling potential in building materials", Building and Environment,vol.42,pp 2311-2320,2007.

[21] T. Alperen, O. Emrah, A. Aysegul, "Waste to energy technologies for municipal solid waste management in Gaziantep", Renewable and Sustainable Energy Reviews., vol.54, pp. 809-815,2016.

[22] Yildirim I.Tosun, "5MW hybrid power generation with agriculture and forestry biomass waste co-incineration in stoker and subsequent solar panel (CSP) ORC station", Renewable Energy Research and Applications (ICRERA), 2015 International Conference, DOI: 10.1109/ICRERA.2015.7418481, 22-25 Nov. 2015.

[23] M. Aziz, T. Oda, and T. Kashiwagi, "Novel power generation from microalgae: Application of different gasification technologies", Renewable Energy Research and Applications (ICRERA), 2015 International Conference, DOI: 10.1109/ICRERA.2015.7418510, 22-25 Nov. 2015.

[24] MNRE (Ministry of New and Renewable Energy). National Master Plan for Development of Waste-to-Energy in India. Ministry of Environment and Forests, 2011.

[25] Saini S, Rao PS, Patil Y,"City Based Analysis of MSW to Energy Generation in India, Calculation of State-wise Potential and Tariff Comparison with EU", Procedia – Social and Behavioral Sciences,vol. 37,pp.407-416,2012.

[26] Mehtab Singh Chouhan, Sanjay Verma, Sarita Sharma, Niraj Metha ,"Review on waste to energy potential in India" ,International Journal of Chemical Studies ,vol.2,pp. 51-53,2015.

[27] Singh L, Sundaresan R, Sarin R,"Waste to Energy Generation from Municipal Solid Waste in India", International Journal of ChemTech Research, vol.6,pp.1228-1232,2014.

[28] Charles Rajesh Kumar.J,Vinod Kumar.D,M.A. Majid ," Wind energy programme in India: Emerging energy alternatives for sustainable growth",Journal of Energy & Environment [Accepted] ,2019.

[29] Physical Progress (Achievements), Ministry of New & Renewable Energy, Programme/Scheme wise Physical Progress in 2018-19 & Cumulative up to July, 2018, <https://mnre.gov.in/physical-progress-achievements>, [Accessed 31.06.2018].

[30] Renewable Energy Generation Report-July 2018, Central Electricity Authority of, 2018.

[31] Shyamala Mani, Satpal Singh, "Sustainable Municipal Solid Waste Management in India: A Policy Agenda", Procedia Environmental Sciences, vol.35,pp.150 – 157,2016.

[32] Waste to Energy and Waste Management Market in India -2018, Examining Opportunities, Economics, Technologies, Market Trends, Challenges & Outlook, enicon, 2018.

[33] CPCB (Central Pollution Control Board). 2000. Management of municipal solid waste Delhi, 2000.

[34] Emmanuel C. Ogbonna ; Rashid Ali ; Georgios Pissanidis, "Simulation model for mesophilic anaerobic digestion heating system", Renewable Energy Research and Applications (ICRERA), 2013 International Conference, DOI: 10.1109/ICRERA.2013.6749807, 20-23 Oct. 2013.

[35] Lakshmi ;J. Refonaa ;J. Vivek, Tracking of biomedical waste using global positioning system, International Conference on Circuits, Power and Computing Technologies,ieeeexplore,2015.

[36] W.A. Rutala, G. Mayhall, "Medical waste, Infection Control and Hospital Epidemiology",vol.13, pp.38-48,1992.

[37] B.-K. Lee, M.J. Ellenbecker, R. Moure-Ersaso, "Alternatives for treatment and disposal cost reduction of regulated medical waste" ,Waste Management.,vol. 24 , pp. 143-151,2004.

[38] E. Insa, M. Zamorano, R. Lopez, "Critical review of medical waste legislation in Spain Resources", Conservation and Recycling, vol.54 , pp. 1048–1059,2010.

[39] Elliott Steen Windfeld; Marianne Su-Ling Brooks, "Medical waste management – A review", Journal of Environmental Management, vol.163(2015), pp. 98-108,2015.

[40] Dipanshu Chinwan,Shubhangi Pant, "Waste to Energy in India and its Management" ,Journal of Basic and Applied Engineering Research,vol.1, pp. 89-94,2014.

[41] Khajuria A, Matsui T, Machimura T, Morioka "Assessment of the challenge of sustainable recycling of municipal solid waste management in

India",International Journal of Environmental Technology and Management,vol.13, pp.171–187,2010.

[42] Samir Saini, Prakash Rao, Yogesh Patil, "City-based analysis of MSW to energy generation in India, calculation of state-wise potential and tariff comparison with EU", International Conference on Emerging Economies –Prospects and Challenges Procedia - Social and Behavioral Sciences, vol.37 , pp. 407 – 416,2012.

[43] Richa Kothari, V.V.Tyagi, Ashish Pathak, "Waste-to-energy: A way from renewable energy sources to sustainable development", Renewable and Sustainable Energy Reviews, vol.14, pp.3164-3170,2010.

[44] Taste success from waste, Opportunities in the Indian solid waste to energy sector, Classification of waste, Report, EAI renewable energy consulting and research.

[45] Waste to Energy-World Energy Resources, World Energy Council, Report, 2016.

[46] Modak P, Jiemian Y, Hongyuan Yu, Mohanty CR, Municipal solid waste management: turning waste into resources. In Shanghai manual: a guide for sustainable urban development in the 21st century, pp. 1–36,2010.

[47] Kumar JS, Subbaiah KV, Rao PVVP, "Municipal solid waste management scenario in India". Australian Journal of Engineering and Technology Research,vol.2 , pp 1–8,2014.

[48] Planning Commission, Government of India. 2014 Report of the Task Force on waste to energy (Volume I) in the context of integrated municipal solid waste management, 2014.

[49] Ranjith Kharvel Annepu, Sustainable solid waste management in India. Waste-to-Energy Research and Technology Council (WTERT), 2012.

[50] Generation of solid waste, The Ministry of New and Renewable Energy (MNRE), Loksabha -Unstarred question no.2974, January 2018.

[51] Rohith Kakkar, Management of Municipal Solid Waste-focus on Waste to Wealth, Ministry of Urban Development, Govt of India,2014.

[52] R.P. Singh, V.V. Tyagi, T. Allen, M.H. Ibrahim, R. Kothari, "An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario", Renewable and Sustainable Energy Reviews, vol.15, pp. 4797- 4808,2011.

[53] R.K. Annepu Sustainable Solid Waste Management in India,Columbia University in the city of New York, Department of Earth and Environmental Engineering, New York ,2012.

[54] E.K. Çoban, C. Gençoğlu, D. Kirman, O. Pinar, D. Kazan and A.A. Sayar "Assessment of the effects of medium composition on growth, lipid accumulation and lipid profile of Chlorella vulgaris as a biodiesel feedstock", Renewable Energy Research and Applications (ICRERA), 2015 International Conference, DOI: 10.1109/ICRERA.2015.7418521, 22-25 Nov. 2015.

[55] Salman Zafar, Waste to Energy Conversion Routes, Bioenergy consult, <https://www.bioenergyconsult.com/waste-to-energy-pathways/ >, [Accessed 19.07.2018].

[56] Bharat Bhushan Nagar, Government incentives for Industrial waste to energy projects in India, USAID low emission Asian development, 2015.

[57] Sunil Kumar, Stephen R. Smith, Geoff Fowler, Costas Velis, S. Jyoti Kumar, Shashi Arya, Rena, Rakesh Kumar, Christopher Cheeseman , "Challenges and opportunities associated with waste management in India" ,Royal society of science,vol.4 ,pp.1-11,2017.

[58] Khanjan Ajaybhai Kalyani,Krishan K.Pandey,"Waste to energy status in India: A short review",Renewable and Sustainable Energy Reviews,vol.31,pp.113-120,2014.

[59] R.P. Singh, V.V. Tyagi, T. Allen, M.H. Ibrahim, R. Kothari, "An overview for exploring the possibilities of energy generation from municipal solid waste (MSW) in Indian scenario", Renewable and Sustainable Energy Reviews, vol.15,no.9, pp. 4797-4808,2011.

[60] M. Sharholy, R. Vaishya, R. Gupta, K. Ahmad, "Municipal solid waste characteristics and management in Allahabad, India" Waste Management, vol.29, pp. 490-496,2007.

[61] D.N. Beede, D.E. Bloom, "The economics of MSW", The World Bank Research Observer journal, vol.10, pp. 113-150,1995.

[62] A.M. Qudais, A.H. Qudais, "Energy content of municipal solid waste in Jordan and its potential utilization" , Energy Conversion and Management, vol.41 , pp. 983-991,2000.

[63] Annual Report 2014-15, Ministry of New and Renewable Energy, Government of India. <https://mnre.gov.in/file-manager/annual-report/2014 2015/EN/Chapter%201/chapter_1.htm>, [Accessed 13.12.2017].

[64] UK-based firms to invest Rs 1,500 cr in waste-to-energy projects in South, The hindu-Businessline,https://www.thehindubusinessline.com/news/national/ukbased-firms-to-invest-rs-1500-cr-in-wastetoenergy-projects-in-south/article9836637.ece,[Accessed 30.08.2018].

[65] Waste to Energy, The Gujarat Cleaner Production Centre (GCPC) Envis center - Industries & Mines Department, Government of Gujarat (United Nations Industrial Development Organization (UNIDO)) Report ,2018.

[66] Power generation from municipal solid waste, MNRE, 20th Report, Standing committee on energy Report, 2016.

[67] Barkha Vaish,Vaibhav Srivastava,Pooja Singh,Anita Singh,Prabhat Kumar Singh,Rajeev Pratap Singh,

"Exploring untapped energy potential of urban solid waste", Energy Ecology Environment journal, vol.1, pp.323-342,2016.

[68] R.K. Annepu, "Waste to energy status in India: A short review", Renewable, and Sustainable Energy Reviews, vol.31, pp 113-120,2014.

[69] Waste-to-Energy Installed capacity 2012- 2016 (state wise), ENVIS Centre of Renewable Energy and Environment, Ministry of Environment, Forest & Climate change, Government of India, <http://terienvis.nic.in/index3.aspx?sslid=4347&subsublinkid=1406&langid=1&mid=1>,[Accessed 12.04.2018].

[70] Energy statistics, March 2017, 24th issue, Central statistics office, Ministry of statistics and programme implementation, Government of India, 2017.

[71] Energy statistics, March 2018, 25th issue, Central statistics office, Ministry of statistics and programme implementation, Government of India, 2018.

[72] Renewable Energy Generation Broad Overview Report, Central Electricity Authority of India, August 2018.

[73] Incentives, New & Renewable Energy Development Corporation of Andhra Pradesh Ltd. <http://nredcap.in/incentives.aspx>, [Accessed 13.01.2018].

[74] Industrial Waste Based Power Projects, New & Renewable Energy Development Corporation of Andhra Pradesh Ltd. <http://nredcap.in/IndustrialWasteBasedPowerProjects.aspx >, [Accessed 12.03.2018].

[75] Urban Waste Based Power Projects, New & Renewable Energy Development Corporation of Andhra Pradesh Ltd.<http://nredcap.in/UrbanWasteBasedPowerProjects.aspx>,[Accessed 02.02.208]

[76] Municipal Waste Based Power Projects, New & Renewable Energy Development Corporation of Andhra Pradesh Ltd. <http://nredcap.in/MunicipalWasteBasedPowerProjects.aspx>, [Accessed 02.02.208].

[77] Waste to Energy Plants Operational in India, <https://www.bestcurrentaffairs.com/waste-energy-plants-operational-india/>, [Accessed 12.12.2017]

[78] Upendra Tripathy, A 21stCentury Vision on Waste to Energy in India: A Win-Win Strategy for Energy Security and Swachh Bharat Mission (Clean India Mission) 22.01.2018, United Nations center for regional development, in collaboration with Ministry of Housing and Urban Affairs (MoHUA), Government of India and Ministry of the Environment, Government of Japan, 2018.

[79] State-wise details of waste-to-energy plants set up with installed capacity and number of plants, Ministry of New and Renewable Energy (MNRE), Lok Sabha starred question No.154. 30.01.2018.

[80] List of Project developers, New & Renewable Energy Development Corporation of Andhra Pradesh Ltd,<http://nredcap.in/ListofProjectDevelopers.aspx,>,[Accessed 20.09.2018].

[81] Online project monitoring system, Establishment of waste to energy projects in Andhra Pradesh, Swachha Andhra Corporation, Department of Municipal Administration & Urban Development, 2017.

[82] Swathi Vadlamudi, Waste-to-energy plant at Jawahar Nagar to cost high <https://www.thehindu.com/news/cities/Hyderabad/waste-to-energy-plant-at-jawahar-nagar-to-cost-high/article24383079.ece>, [Accessed 11.07.2018].

[83] Petition of Nagpur Solid Waste Processing and Management Private Limited, Case No.158 of 2017, 05.02.2018, Maharashtra Electricity Regulatory Commission, 2018.

[84] Tamilnadu Electricity Regulatory Commissions, PPAPNo4of2017, Pallavapuram Tambaram MSW Private Limited, 2017.

[85] India's largest solid waste-to-energy plant launched at Delhi's at Narela, Hindustan Times, <https://www.hindustantimes.com/delhi-news/municipal-corporation-inaugurates-india-s-largest-solid-waste-to-energy-plant-at-narela/story-dZuZaGLV3UFQPzU8vmSbyM.html>,[Accessed 10.03.2017]

[86] Pengfei Sheng, Yaping He, Xiaohui Guo, "The impact of urbanization on energy consumption and efficiency", Journal of Energy and Environment, vol.28, pp .637-689,2017.

[87] Ministry of Environment and Forests (MoEF), the Gazette of India. Municipal solid waste (Management and Handling) rules, New Delhi, India, 2015.

[88] Guria N, Tiwari VK, "Municipal solid waste management in Bilaspur city (C.G.) India", National Geographer, Allahabad ,vol.1, pp.1–16,2010.

[89] Das S, Bhattacharya BK, "Estimation of municipal solid waste generation and future trends in greater metropolitan regions of Kolkata", Journal of Industrial Engineering and Management Innovation, vol.1, pp.31–38,2014.

[90] Bhoyar RV, Titus SK, Bhide AD, Khanna P, "Municipal and industrial solid waste management in India". J. IAEM, vol.23, pp. 53–64,1999.

[91] The United States Environmental Protection Agency (USEPA). Solid waste management: a local challenge with global impacts,2002.

[92] Sadhan Kumar Ghosh, "Sustainable SWM in developing countries focusing on faster growing economies, India and China", International Conference on Solid Waste Management, Procedia Environmental Sciences,vol. 35,pp.176 – 184,2016.

[93] Mathur V, “Scope of recycling municipal solid waste in Delhi and NCR- integral review”, Journal of Management,vol.5, pp. 27–36,2012.

[94] Wilson DC, Velis C, Cheeseman C, “Role of informal sector recycling in waste management in developing countries”, Habitat Int,vol.30, pp. 797–808,2006.

[95] Annepu RK,”Report on sustainable solid waste management in India” Waste-to-Energy Research and Technology Council (WTERT) ,pp.1-189,2012.

[96] G. Kiely, Environmental Engineering, McGraw Hill, UK 1997.

[97] M. Luoranena, R. Soukkaa, G. Denafasb, M. Horttanainen, Comparison of energy and material recovery of household waste management from the environmental point of view – Case Kaunas Lithuania, Applied Thermal Engineering, vol.5, pp. 938-944,2009.

[98] L. Giusti, “A review of waste management practices and their impact on human health”, Waste Management, vol.8 , pp. 2227-2239,2009.

[99] C-Tech Innovation Ltd, Biffaward programme on sustainable resource use – thermal methods of municipal waste treatment, Capenhurst Technology Park, Chester, UK ,2003.

[100] Waste Incineration and Public Health,Chapter: Incineration Processes and Environmental Releases, the new national academic press, page 34,2000.

[101] Waste-to-Energy Options in Municipal Solid Waste Management, A Guide for Decision Makers in Developing and Emerging Countries, Internationale Zusammenarbeit (GIZ) GmbH,2017.

[102] A.W. Larsen, T. Astrup, “CO_2 emission factors for waste incineration: influence from source separation of recyclable materials”, Waste Management, vol.31 ,pp. 1597-1605,2011.

[103] R. Dvorak, P. Chlapek, L. Hanak, F. Jedlicka, P. Stehlik, “Catalytic filtration of flue gases polluted by Nox”, Chem Eng Trans, vol.21 , pp. 799-804,2010.

[104] O. Gohlke, T. Weber, P. Seguin, Y. Laborel, “A new process for NOx reduction in combustion systems for the generation of energy from waste”, Waste Management, vol.30 , pp. 1348-1354,2010.

[105] D. Jecha, P. Chlapek, R. Dvorak, L. Bebar, “Absorption clearing of flue gas with special focus on SO_2 elimination”, Chemical Engineering Transactions, vol.21 , pp. 619-624,2010.

[106] Q. Falcoz, D. Gauthier, S. Abanades, F. Patisson, G. Flamant, “A general kinetic law for heavy metal vaporisation during municipal solid waste incineration”, Process Safety and Environmental protection, vol.88 , pp. 125-130,2010.

[107] European Parliament and the Council, Directive 2000/76/EC of 4 December 2000 on the incineration of waste, Official Journal of the European Communities, vol.28 , pp. 91–119,2000.

[108] A. Porteous, “Energy from waste incineration—a state of the art emissions review with an emphasis on public acceptability, Applied Energy, vol.2, pp. 157-167,2001.

[109] Negative Impacts of Incineration-based Waste-to-Energy Technology, Alternative energy news, and information about renewable energy technologies. <http://www.alternative-energy-news.info/negative-impacts-waste-to-energy/>, [Accessed 08.07.2017].

[110] Paolo Boffetta, Kenneth A Mundt, Hans-Olov Adami, Philip Cole, Jack S Mandel, TCDD and cancer: A critical review of epidemiologic studies,vol.41, pp 622-636,2011.

[111] Salman Zafar, Medical Waste Management in Developing Countries, Bioenergy consult,<https://www.bioenergyconsult.com/tag/biomedical-waste/>, [Accessed 12.12.2017].

[112] Guidelines for Management of Healthcare Waste as per Biomedical Waste Management Rules, Directorate General of Health Services Ministry of Health & Family Welfare,2016.

[113] CC.Lee, G.L.Huffman, “Medical waste management/incineration”, Journal of Hazardous Materials, vol.48, pp 1-30,1996.

[114] Charles O.Velzy, M.Trichon, “Incineration technology for managing biomedical wastes”, Waste Management & Research,vol. 8, pp. 293-298,1990.

[115] Janusz Wojciech Bujak, “Production of waste energy and heat in hospital facilities”, Energy, vol.91, pp. 350-362,2015.

[116] The pre-feasibility report, Godavari bio management, state-level environmental impact assessment authority, Andhra Pradesh, Government of India, 2016.

[117] Abhay Kumar Sharma, R.K. Ranjan, Surendra Sing, “Best Energy from lethal Biomedical waste”, International Journal of Scientific Research Engineering & Technology,vol.1, pp.073-078,2013.

[118] Salman Zafar, Waste-to-Energy in India, Bioenergy consult, 2016, https://www.bioenergyconsult.com/waste-to-energy-india/,[Accessed 21.04.2018].

[119] S.Bag, N. Mondal, R. Dubey, “Modeling barriers of solid waste to energy practices: An Indian perspective”, Global Journal of Environmental Science and Management, vol.2, pp.39-48,2016.