



## WASTE MANAGEMENT BY “WASTE TO ENERGY” INITIATIVES IN INDIA

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### ABSTRACT

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This century is known for exponentially growing population and development but with huge waste production. The waste produced requires land, labour and capital to for treatment and disposal of such huge amount of waste. In India, people throw or consider it as waste after single use so Indian waste can be good resource for recovery of various products. The waste produced is difficult to manage using conventional methods and is ever increasing, blocking essential land that has become an expensive commodity in today's world. This work explores the current practices of the various waste management initiatives and a critical assessment of traditional waste to energy procedure adopted in India. It gives an overview of the various waste management systems in India. Suggestions for improving the health of society, waste management processes, process performance, environmental assessment parameters to plasma gasification,-an alternate waste to energy has been also discussed. Recommendation has been made for the micro-waste plant to solve the waste challenges.

**Contribution/Originality:** The main contribution of the paper is to assess waste management in India and certain waste emerging innovations –Waste to Energy, which are technically applicable and relevant. It also addresses how the use of advanced waste technologies like plasma can be a way of achieving a circular economy as well as less environmental impact.

### 1. INTRODUCTION

Energy is one of the foods for technical or economic development of human beings. Rapid increase in population has resulted in huge demands for energy to for material production. Such thrust for energy and to recover more energy requires technological exploitation of energy resources (Ramos & Rouboa, 2020; Young, 2010). The materials byproducts are related to waste, an inevitable by-product of industrial production. The exponentially growing population has increased the waste production to many fold. Although waste is shown to be a non-essential qualitative component of industrial production, the quantitative scope of waste can vary according to the degree of (in)efficiency with which these processes are operated within certain limits. Over the years, the invention of new products, innovations and facilities has altered the quantity and quality of waste. Waste characteristics do not only depend on income, culture and geography but also on a society's economy and situations

like disasters that affect that economy (Ionescu et al., 2013; Kumar, Khare, & Alappat, 2002; Kumar, 2014; Kumar, Kumar, & Singh, 2020; Kumar & Samadder, 2017; Leena, Sunderesan, & Renu, 2014; Rawat, Kaalva, Rathore, Gokak, & Bhargava, 2016; Vats & Singh, 2014; Vats & Singh, 2014).

**Table-1.** MSW waste estimate with population.

Year	Population (in million)	Total waste generation (million MT/year)(@0.4kg/capita/day)	Total waste generation (million MT/year) (@0.6kg/capita/day)
2015	1310.15	191.2819	286.9229
2020	1381.59	201.7121	302.5682
2025	1450.52	211.7759	317.6639
2030	1503.64	219.5314	329.2972
2035	1553.723	226.8436	340.2653
2040	1592.69	232.5327	348.7991
2045	1620.61	236.6091	354.9136
2050	1639.17	239.3188	358.9782

Note: \*population data from worldometer web.

Waste challenges in metropolitan centers include the growing challenge of acquiring expensive land for disposal, producing emissions from waste treatment and disposal, etc (Sharma & Shah, 2005; Vats & Singh, 2014). The disposal of waste has caused resource depletion and the huge cost involved in waste processing and transportation.

Established processes for the collection, transport and treatment of solid waste are mired in confusion in India. Uncontrolled waste disposal has created overflowing landfills on the outskirts of neighborhoods, which are not only very difficult to retrieve due to haphazard dumping practices, but can have significant environmental effects in terms of water contamination, land degradation and air pollution that lead to global warming. Environmental degradation is taking place and organizations that are responsible for environmental management are facing many problems and challenges. Uncontrolled waste disposal and unsustainable waste management not solely harm the atmosphere, but conjointly have an effect on human health (Central Pollution Control Board (CPCB), 2004; Jha, Singh, Singh, & Gupta, 2011; Kumar & Samadder, 2017). The new scheme relies on the storage and transport of mainly mixed, unsegregated waste.

The 5R solution - Recycling, Reduce, Reuse, Refuse, Recover, Residual Management with sustainable disposal of residual waste in science-based landfills is grossly ignored (Abhishek & Mukherjee, 2019; Alam & Ahmade, 2013; Anubhav, Abhishek, & Durgesh, 2012; Cleary, 2009; Kumar et al., 2017; Nandan, Yadav, Baksi, & Bose, 2017; Otitoju & Seng, 2014; Srinivas, 2007; Sudha, 2008; UN, 2000; World Energy Council Report, 2013; Young, 2010). This work explores the solid waste production status and its environmental and financial impact on Indian cities. This study also analyses the growing number of municipal solid waste (Kumar et al., 2016; Sudha, 2008; World Energy Council Report, 2013) the changing nature of municipal solid waste, from biodegradable waste, dry waste to the increasing volume of plastic in the waste (Cleary, 2009; Devi & Satyanarayana, 2001; Hargreaves, Adl, & Warman, 2008; Indo-UK Seminar Report, 2015; Jha et al., 2011; Kumar & Samadder, 2017).

This work also presents the sources of waste-to- energy / energy-from-waste conversion technology for the solid waste sector. Laws for sustainable solid waste disposal have already been set in motion, but a big obstacle is the need to plan and maintain the scheme and ensure implementation of the rules (Sharma & Shah, 2005; Vats & Singh, 2014).

In addition to providing some mitigation options to respond to the growing problem, current governments recommend publicly-engaged frameworks to ensure that the framework is financially sustainable. There are many cleaner technologies for dealing with waste but lack of knowledge and public awareness makes waste management a menace. Public participation is required to deal with the generated waste at source itself.

## 2. MUNICIPAL SOLID WASTE IN INDIAN CONTEXT

India, the second most populated country in the world and one of the fastest-growing economies, is experiencing unprecedented growth in its industrial sector and is undergoing rapid urbanization. The population of India is approximately 1.3 billion and experts believe that each day a single person is generating 450 grams of waste (Central Pollution Control Board (CPCB), 2000, 2004; Kumar et al., 2016).

Current rate of municipal waste projection as per population growth is shown in Table 1. The study predicts that MSW generation will reach 219- 330 million MT/year by 2030 and 240-358 million MT/year by 2050. Much variability of per capita waste generation is found in accordance with the size and class of the cities. As per CPCB report, in 2012, 1,27,486 tons per day of MSW is being produced from household activities and other commercial & institutional activities (Abhishek & Mukherjee, 2019; Kumar et al., 2016; World Energy Council Report, 2013).

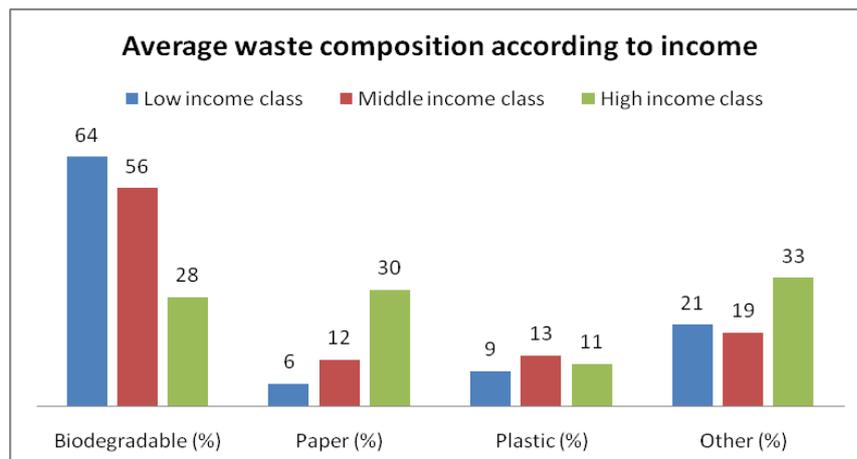


Figure-1. Waste composition with different income class.

Source: Kumar and Samadder (2017).

There is no difference in the types of waste generated in the physical characterization data of MSW in metropolitan cities of India for the last 2 decades, although there is an increase in the quantity of waste produced. Figure 1 show that the urban MSW in India can be classified as 40-50% biodegradables, 15-20% recyclables and 31% of inert wastes with moisture content of 47% and average calorific value of 7.3 MJ/k (Jha et al., 2011; Kumar et al., 2017; Kumar et al., 2020; Leena et al., 2014).

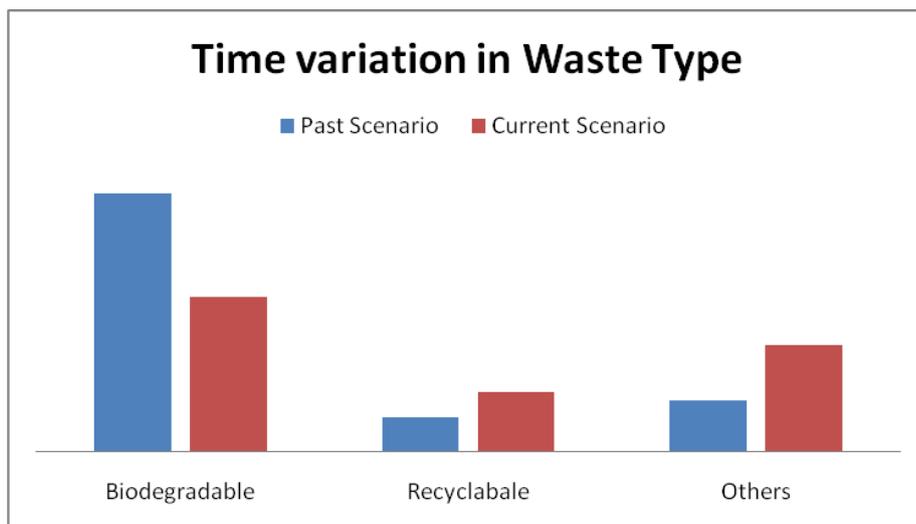


Figure-2. Changing waste scenario.

Source: Abhishek and Mukherjee (2019); Nandan et al. (2017); Paulraj, Bernard, Raju, and Abdulmajid (2019).

The 20<sup>th</sup> century has led to drastic change in the type of waste produced as shown in Figure 2. Earlier, there were large quantity (70-80%) of biodegradable waste but there is only 45-50% of biodegradable waste and 50% of other waste including plastic, paper, hazardous, biomedical etc (Abhishek & Mukherjee, 2019; Nandan et al., 2017; Paulraj et al., 2019). Higher consumerism, rapid population growth with unplanned urban development, and lifestyle changes have led to increased volumes in solid waste as well as more plastics and certain inorganic materials contents.

The generated waste engagement is not a new cup of tea, but a long pending and ignore field in view of low quantity. The rapid increase in population and industry has grown as shown in data table. The searches for new and new technology are in force, as it has started affecting the human beings. The method like composting, bio-methanation and combustion are few oldest methods for waste treatment in India, but limited to organic waste like food / plant material. They basically target organic waste biological decomposition with /without the presence of oxygen, e.g. bio-methanation, combustion. The biggest advantage of such technique is that it does not only reduce nature affecting gas like methane, but also generates – a powerful greenhouse gas. It can simultaneously generate electricity, cooking gas and inert residue which can be used as manure. One of the biggest limitations of these processes is the long and spacious process. Therefore, their rate of treatment fails to target the amount of waste generated, and men has started using the landsite near /outside man colonies for waste treatment and safety issues. Land filling has emerged as one of the cheapest and easiest methods of SWM; burns on low level areas are target areas of dumping solid waste thus leveling the ground for useful purpose. Neither manmade technologies nor nature is capable to treat this huge quantity of waste. The escaped harmful gases and products have started affecting the environment and mankind.

The traditional solid waste management processes, such as composting, bio-methanation and land filling, suffer from the disadvantage of environmental deterioration and space problem, as composting and bio-methanation requires large area for treatment and it takes long period of time. For land disposal of solid waste, India needs 1,240 hectares of extra valuable land every year to include untreated solid waste. As per report published by Ministry of Urban Development, government of India, 2014, Solid waste produced was 133000 MT/day, Total waste collected is 91000 MT/day, waste littered 42000 MT/day, from the collected MSW 26000MT/day is treated and 66000 lakh MT/day landfilled (crude dumping). The waste generated is 133000 MT/day and waste collected, treated, littered and land filled has been shown in Figure 3.

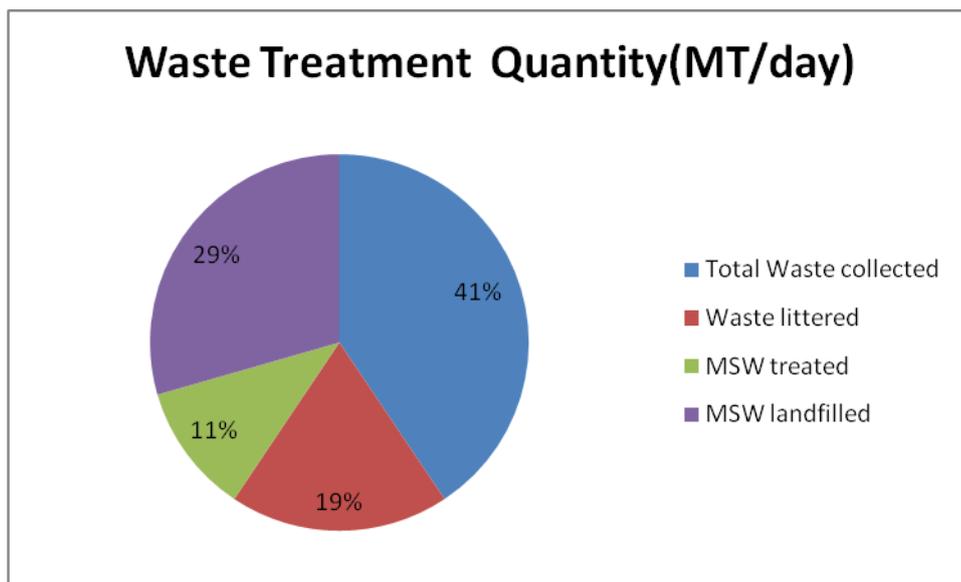


Figure-3. Current municipal waste management.

Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020).

Figure 4 show a comparisons of various state waste segregation in % .

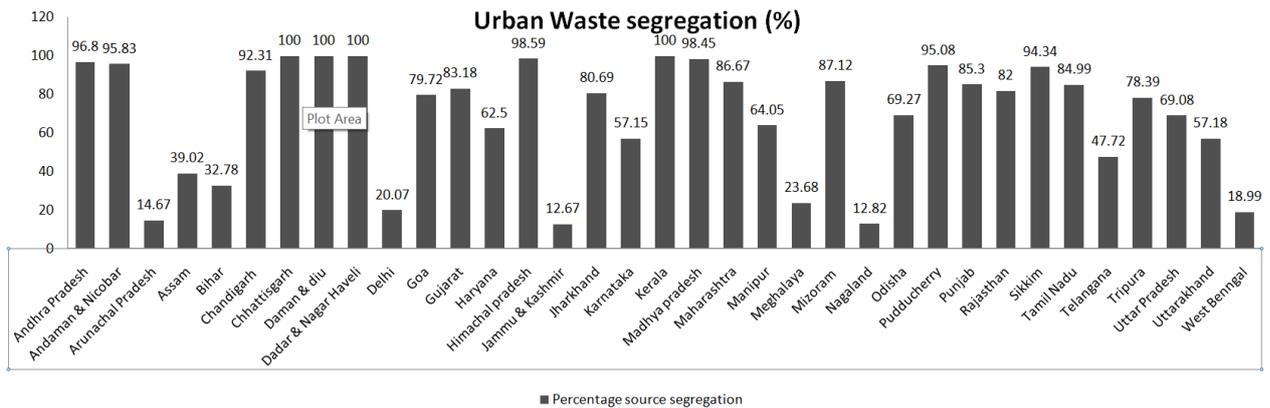


Figure-4. State wise percentage waste segregation.

Date Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020); Sudha (2008).

The calorific value of Indian municipal waste ranges from 800 Kcal to 1100 Kca and moisture content 40% to 50% .The traditional techniques are time taking processes so heap/ mountain of waste has formed which has affected the aesthetic beauty of the city; and in these processes, foul smell is produced and also contributed to many environmental problems, such as global warming, ozone depletion, human health hazards, ecosystem damages, abiotic resource depletion, etc. (Khandelwal, Dhar, Thalla, & Kumar, 2019). This further leads to a lack of public approval for new waste management sites. The existing landfill sites in mega cities like Delhi, Kolkata and Mumbai have dangerously exceeded their capacity already. Moreover, the traditional waste disposal technique by landfill is considered the most unfavorable route in the waste management hierarchy, as it wastes valuable land and gives rise to Green House Gases (GHG) emissions, primarily methane (Khandelwal et al., 2019).

### 3. MODERN TECHNOLOGIES FOR MUNICIPAL SOLID WASTE MANAGEMENT (MSWM)

The various studies have been conducted on traditional waste management methods based on cost of the technology, environmental impact assessment, life cycle etc. Top 5 cities in waste processing is shown in Figure 5 (Satpal, 2020). The performance of applied methods is based on their geographical location, and input waste type. All the traditional technologies have shortcomings of waste generation, time required and ash content produced so there is a need of technological advancement in this field which can overcome all these limitations.

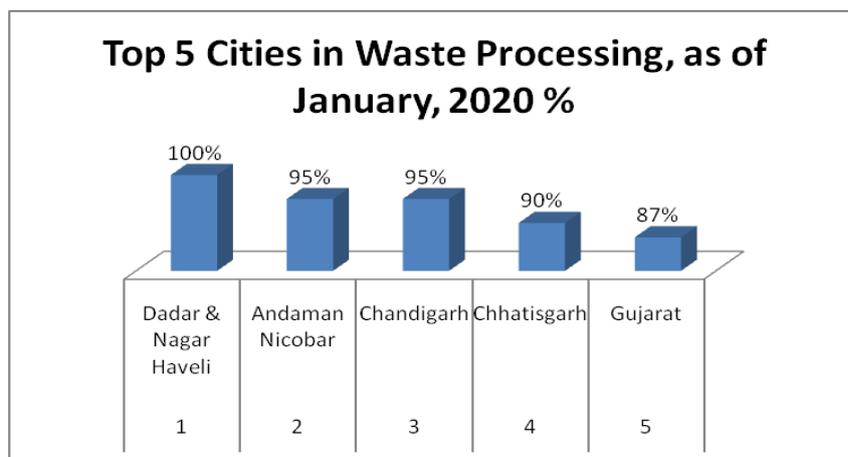


Figure-5. Top 5 cities in waste processing (JAN, 2020).

Source: Central Pollution Control Board (CPCB) (2000) and Satpal (2020).

The various methodologies for waste to energy (WtE) have evolved from combustion, gasification, incineration (Table 2). The different processes of thermo chemical treatment, such as composting, incineration, pyrolysis, etc., are an essential component of the management system of sustainable integrated municipal solid waste (MSW) (Kumar & Samadder, 2017; Otitoju & Seng, 2014; Sudha, 2008). Thermal treatment plants can in fact convert MSW into different energy forms, such as electricity and heat for both utilization in industrial facilities or district heating (Kumar, 2013; World Energy Council Report, 2013; Young, 2010). The advancement in technologies for solid waste management cannot limit generation of waste, the only possible solution can be to help nature to convert waste into natural components. From combustion, gasification, incineration to plasma technology (Abhishek & Mukherjee, 2019; Paulraj et al., 2019) various waste-to-energy (WtE) methodologies have emerged. All WtE itself needs additional material and energy resources and waste as a resource and contributes in absolute terms to a decrease in per capita waste generated (Devi & Satyanarayana, 2001). Table 2 show such WtE plants with energy generation in various Indian cities.

Table-2. Modern technologies for Municipal Solid Waste Management.

	Combustion	Land filling	Incineration	Gasification	Pyrolysis
Aim of the process	Waste to high T flue gases	Maximize waste decomposition,	Waste conversion to high temperature	Waste to high heating value flue gases	Max. thermal decomposition of solid
Flue Gases	CO <sub>2</sub> , H <sub>2</sub> , CO, H <sub>2</sub> O and particulate matter.	CO <sub>2</sub> and CH <sub>4</sub>	CO <sub>2</sub> and H <sub>2</sub> O	CO, H <sub>2</sub> , CO <sub>2</sub> , H <sub>2</sub> O and CH <sub>4</sub>	CO, H <sub>2</sub> , CH <sub>4</sub> and other hydrocarbons
Operating condition reaction environment	Oxidant amount larger than required) in presence of air.	Oxidizing at the upper layer and reducing beneath the surface.	Oxidant amount larger in presence of air between 850°C and 1200°C	Lower oxidant in oxygen enriched air, steam Between 550°C and 900° C (in air gasification) and 1000-1600° C	Total absence of any oxidant between 500°C and 800°C
Pressure P	Atmospheric	Atmospheric	Generally atmospheric	Generally atmospheric	Slight over-pressure
Pollutants	CO <sub>2</sub> , H <sub>2</sub> , CO, H <sub>2</sub> O and particulate matter.	CO <sub>2</sub> , CH <sub>4</sub> , SO <sub>x</sub> , NO <sub>x</sub> H <sub>2</sub> , CO, H <sub>2</sub> O & particulate matter.	SO <sub>2</sub> , NO <sub>2</sub> , HCl, PCDD/F, particulate	H <sub>2</sub> S, HCl, COS, NH <sub>3</sub> , HCN, tar, alkali, particulate	H <sub>2</sub> S, HCl, NH <sub>3</sub> , HCN, tar, particulate
Ash	Large amount of ash is produced.	No ash	Ash – ferrous, non-ferrous metals and inert materials for sustainable utilization.	Vitreous slag that can be utilized as backfilling material	Non- negligible carbon content
Gas cleaning	-	-	Can be made under emission limits	Possible to have clean synthetic gas to meet the standards of chemicals production processes or with high efficiency energy conversion devices	
Waste reduction (w/w)	60%	10-20%	70%	82%	84%
Ash production	Yes	No	Yes	Yes	Yes

Source: Abhishek and Mukherjee (2019); Paulraj et al. (2019); Kumar et al. (2020); Young (2010).

As per 2020 study, almost every state process waster for WtE and Figure 5 show top 5 waste processing cities. Owing to the increasing collection, recycling and reuse of waste are economically viable choices since a large portion of the waste management budget is used to collect and transport waste (Devi & Satyanarayana, 2001;

Khandelwal et al., 2019). Such utilization establishes waste as resources and contributes to the circular economy as a key. Thus, parameters such as the investment, the return period and the monetary revenue constitute challenges to overcome so as to implement this environmentally favorable technique.

Table-3. Operating WtE plant in India

Operational WtE plants in India			
Location	Developer	Capacity (TDP)	Electricity Generation (MW)
Delhi-Okhla	Jindal	1950	16
Delhi- Gazipur	IL&FS	1300	14
Delhi- Bawana	Ramky	2000	24
Hyderabad	Ramky	2400	20
Hyderabad	IL&FS	1000	11
Chennai	Essel	300	2.9
Jabalpur	Essel	600	0.9
Shimla	Elephant Energy	70	1.75

Source: Municipal bodies of different cities/ miscellaneous.

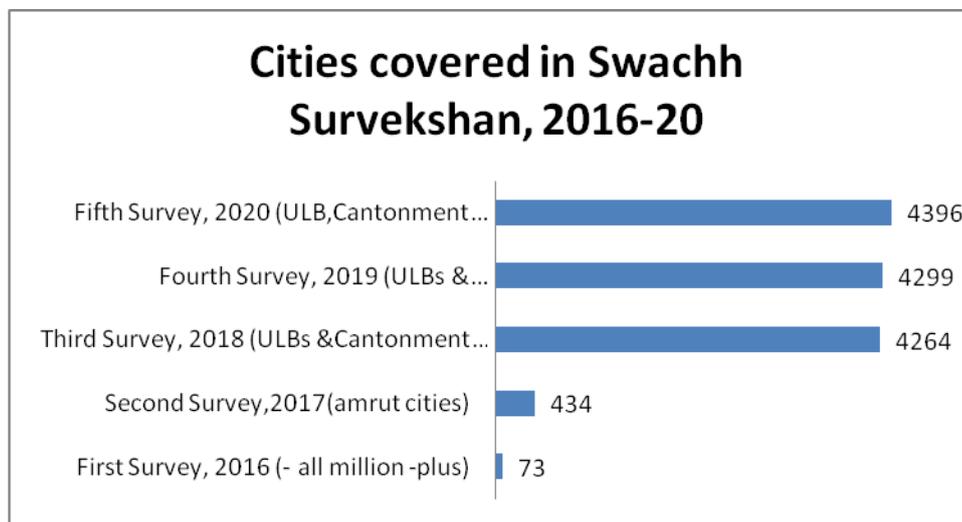


Figure-6. Cities covered in swachh survekshan.

Source: Kumar (2013); Rada, Istrate, and Ragazzi (2009), Central Pollution Control Board (CPCB) (2000) and Satpal (2020).

#### 4. MSW SOCIAL APPROACH

The various waste planning approaches are based on waste generation quantities, local waste characteristics, local geographical conditions, land accessibility and other relevant criteria. The large volume of waste places special emphasis on community or stakeholder contribution and inter-departmental coordination at the local-authority level to ensure implementation success. The easiest way to reduce waste reaching landfill sites is by involving more stakeholders like NGOs, local people and other organizations. This can be achieved by spreading education and awareness among people about waste as resource, it will help in saving money (Kumar, 2013; Rada et al., 2009).

In this context, various Indian government Initiatives for waste management like Urban Infrastructure Development Scheme for Small & Medium Towns (UIDSSMT), “Recycled Plastics Manufacture and Usage Rules (1999), The Plastics Manufacture and Usage (Amendment) Rules (2003), Central Pollution Control Board (CPCB), Non-biodegradable Garbage (Control) Ordinance, 2006, Municipal Solid Wastes (Management and Handling) Rules, 2000, Swachh Bharat Mission(2014) , Solid Waste Management Rules (2016), are few of them. The government of India also understand the importance of public participation either at source level or management level so public participation has increased from 2016-2020 in Swachh Survekshan (Satpal, 2020) as shown in Figure 6. The sustainable waste management of solid waste without public participation is not possible.

## 5. PLASMA TECHNOLOGY AS AN ALTERNATIVE FOR INDIAN MSW MANAGEMENT

Plasma is the ionized state of matter and is created through the application of energy sourced from electric discharges of frequencies ranging from Direct Current (DC) to the optical range. It is formed whenever ordinary matter is heated over few thousand degree C, which results in electrically charged gases or fluids. The various developing countries have started using plasma as a most feasible solution to the impending and escalating waste management crisis from household waste to other hazardous wastes such as medical wastes. The plasma treatment is based on their high temperature, intense and non-ionising radiation nature. Thermal plasmas can be used to treat all kinds of waste streams, be it solid such as regular MSWs, liquid such as urine or poisonous gases. Due to the high temperature and high energy density generated by thermal plasma, a large throughput can be accommodated with a small scale reactor. The high flux densities generated by the plasma at the reactor boundaries lead to a rapid attainment of steady state conditions, effectively reducing the start-up and shutdown times. The plasma for MSW is effective in two forms. - Plasma pyrolysis and Plasma gasification (Kumar et al., 2020).

Plasma pyrolysis is the combination of thermal-chemical properties of plasma with the pyrolysis process. It completely decomposes waste material into simple molecules with use of extremely high temperatures of plasma-arc in an oxygen starved environment. This technology is particularly appropriate for treatment of solid waste and can also be employed for destruction of toxic molecules by thermal decomposition. Unlike incinerators, segregation of waste is not required in this process. Another advantage of plasma pyrolysis is the reduction in volume of waste, nearly 95%. The numerous advantages of plasma technology it is evident that in the near future, plasma pyrolysis reactors will be widely accepted for toxic waste treatment. The quantity of toxic emissions (dioxins and furans) is much below the accepted emission standards and does not require segregation of hazardous waste. In addition, the disease causing micro-organisms are completely killed and there is a possibility to recover energy.

In plasma gasification, waste is heated to temperatures anywhere from about 1000–15,000°C (1800–27,000°F), but typically in the middle of that range, melting the waste and then turning it into vapor. The end result is the production of synthetic gas (syngas), composed pre-dominantly of carbon monoxide and hydrogen, although certain percentage of carbon dioxide and hydrochloric acid are present, along with vitrified slag which contains molten form of all the inorganic components such as metal scrap present in the MSW feed along with any residual toxic components in inert form. The syngas can be piped away and burned to make energy (some of which can be used to fuel the plasma arc equipment), while the "vitrified" (glass-like) rocky solid can be used as aggregate (for road building and other construction). Plasma gasification used for MSW would require no sorting of materials, eliminate the need for landfills, remove long-haul trucking from our roads and be financially viable. Syn gas can also be converted into high-value products such as highly pure hydrogen, fuels, and other valuable chemical compounds.

Plasma is the sole source of heat in both technologies. No combustion takes place and the end result is the production of synthetic gas (syngas). In fact, the syngas may be contaminated with poisonous gases such as dioxins that must somehow be scrubbed out and disposed of, although some contaminated material may also be found in the rocky solid. Such revenue generation can make it financially viable (Kumar et al., 2020). Plasma gasification used for MSW would require no sorting of materials, eliminate the need for landfills, remove long-haul trucking from our roads and be financially viable.

## 6. PLASMA TECHNOLOGY ASSESSMENT

The plasma technology has many challenges such as high installation cost, moderated community readiness level, requirement of proper waste sorting less popular, limited process understanding. Because of congested and narrow roads, no single collection mode is effective, economical and efficient in India. Because of the heterogeneity of urban waste, the process of selecting the right waste disposal method is complex. Appropriate method of waste disposal can save money and avoids future problems. The cost of plasma technology is relatively high as compared to other technologies but the cost can be balanced with the revenue generation by selling of the products such as

electricity generation from syn gas. This technology is solving many problems such as ash disposal. All technologies require land for ultimate disposal of waste but plasma technology is returning all material in atomic form back to the nature/environment.

The rapid increase in population is also affecting the electricity demand of the country. The current available energy supply is much lower than the actual energy demand for consumption in many of the developing countries. At present, major source of energy throughout the world is fossil fuels that meet the demand of approximately 84% of the total electricity generation. With the use of plasma technology, the generated electricity can serve as a potential to overcome the energy demand and load on fossil fuels. The Plasma gasification technology is relatively new and people have limited awareness about the technology also people have various safety concerns about its extreme process conditions so it was rated at a moderate community readiness level. These observations may also be due to plasma gasification being a relatively new technology for waste-to-value processing and waste management, the current lack of standards and government regulations, a limited number of prototype units, and scepticism of environmental effects of the technology. From a practical point of view, it is necessary for plasma gasification to have higher levels of CRL and general public approval. Regardless of how sound its technical concept is, if the public is concerned about the technology then politicians, companies, or end-users will be less motivated towards the implementation of such a technology.

Public readiness can be improved by spreading public awareness about waste to value technology. Health equipments and kits can be developed for the operator to make it safe for health of the people working on the plant. Technology readiness levels assessment examine a technology based on requirement, concept and capabilities on a scale of 0 to 9 with 9 being the most mature technology. The plasma gasification technology is rated moderate to high as it partially achieved the first eight levels of TRL.

All technologies require large area for installation, operation and transportation of waste. To overcome this problem, small plants of plasma technology can be in-situ installed. The small plasma technology plant can be installed at a community level or it can be installed in hospitals etc. this will reduce the cost of transportation as well as reduce the traffic on roads from trucks transporting waste. The products can be utilized at the community level itself or it can be sold in market. All technologies have pros and cons related in their application. Considering all the fields and cost to benefit ratio, plasma technology can be said as suitable option for treatment of all type non-biodegradable waste in India.

## 7. DISCUSSION

The amount of MSW produced in India is rapidly increasing because of population increase and lifestyle change. The utilization of traditional methods for waste treatment isn't sufficient to handle such an outsized quantity of waste. Now Indian government has understood the gravity of the waste management problem, and shifting to science-based solution of waste to energy conversion. The installation of such waste plant at community level can solve our problem. The multiple approaches with the assistance of plasma waste technology through public participation will eliminate the necessity for landfills, remove long-haul trucking from our roads. Government understands the necessity of public involvement and initiated several policies, activities and initiatives like Swatchhta bharat, Zero plastic use in solving MSW problem. Implementation of such policies will help to extend the share recycling of waste and re-using, an economically attractive option. Plasma based WtE is comparatively new technology which has high technical value, high efficiency, high installation cost, but with low awareness level and safety. the top product syngas features a high revenue generation capacity which may make it financially viable and may be a proven solution for all MSW- burning issue in India.

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**Acknowledgement:** All authors contributed equally to the conception and design of the study.

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