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# Solid Waste Management in India An Assessment of Resource Recovery and Environmental Impact

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**Abstract**

This study analyses the environmental and financial sustainability of solid waste management in Indian cities. It presents an assessment of the rapidly rising volume of municipal solid waste, its changing composition, the continuing practice of mixing biodegradable (wet) waste with dry waste at the source of generation, and the growing volume of plastic in the waste. The present system is focussed on collection and transportation of largely mixed unsegregated waste. Resource recovery from the waste and safe disposal of the residual waste in scientifically designed landfills are grossly neglected. Rules have now been put in place for sustainable solid waste management, but the capacity to plan and manage the system and ensure the enforcement of the rules is a major challenge.

The inability to ensure segregation of waste comes in the way of proper recycling, effective functioning of biomethanation plants, and also of safe operation of waste to energy plants which consequently leads to release of toxic pollutants into the atmosphere. Sites allocated for landfills are used as open dumping sites where far too much waste is dumped without resource recovery, generating leachate and methane gas.

This study also presents the sources of greenhouse gas emissions from the solid waste sector. Besides presenting some mitigation choices to respond to the growing challenge, it also suggests mechanisms for ensuring that the system is financially sustainable.

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**Solid Waste Management in India**

**An Assessment of Resource Recovery and Environmental Impact**

Isher Judge Ahluwalia and Utkarsh Patel

## 1. Introduction

Rising incomes, rapidly growing but unplanned urbanisation, and changing lifestyles have resulted in increased volumes and changing composition (increasing use of paper, plastic and other inorganic materials) of municipal solid waste in India. The volume of waste is projected to increase from 64-72 million tonnes at present to 125 million tonnes by 2031. Untreated waste (a mixture of biodegradable or wet waste and non-biodegradable waste) from Indian cities lies for months and years at dumpsites where land was originally allocated for developing landfills for safe disposal of only the residual waste.

The decomposition of organic matter in the airless heaps of waste at these dumpsites contributes to global warming by Green House Gas emissions. Since the present generation of waste is also not handled effectively, it exacerbates the problem. Ideally, the infrastructure and delivery mechanisms for solid waste management, drainage, sewerage, and waste water treatment should be planned and implemented in a co-ordinated framework of a city development plan. Besides paying attention to ameliorate the immediate environmental and public health crises resulting from the current very poor state of solid waste management, there is need for a clearly articulated medium term strategy to address the challenges of solid waste management in Indian cities.

An effective strategy for managing waste has to start with segregation of solid waste at the source of generation and the treatment of different components of the waste in appropriately different ways, thereby reducing the residual waste that may otherwise go to landfills. While the principles of solid waste management are being better understood and more discussed in public domain, no Indian city has achieved a holistic solution to the challenges of solid waste management. The attention on the part of city officials to collection of segregated waste and its transportation, treatment/processing, recycling and safe disposal is still in a nascent stage. Consumer behaviour patterns in Indian cities have also not adapted to facilitate the process of management of this waste by segregating organic or biodegradable waste from other waste at the source of generation.

Once segregation of biodegradable waste is accomplished, decentralised processing of this waste through composting and/or biomethanation can help reduce the burden of transportation of waste to long distances and also reduce leachate and GHG emissions which stem from dumping mixed waste at dumpsites. While new and varied technological options for processing non-biodegradable waste into energy have emerged, the presence of mixed

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waste in the absence of segregation poses several challenges including that of air pollution with the use of these technologies. An enforceable regulatory regime for emission control is critical for avoiding air pollution caused by many of these technologies. Moreover, efficient conversion of waste to energy depends crucially on whether the waste is of sufficiently high calorific value, and India's municipal solid waste because of its high biodegradable content and also high recycling, falls much short of the threshold calorific value.[1]

Solid Waste Management Rules (2016) provide a reasonable framework to address the multiple challenges of municipal solid waste management in India.[2] They are a significant improvement over the Municipal Solid Waste Management Rules (2000), which was the first time such rules were ever notified for Indian cities.[3] Strategic direction and funding by the Government of India through national missions such as JNNURM, AMRUT, Smart Cities and *Swachh Bharat Mission* have also created an environment in which there is more but by no means adequate focus on the problem. It is extremely important to translate the vision from the Rules and the Missions into an operational integrated strategy of solid waste management.

The analysis in this study suggests that the urban local governments will have to be empowered to take charge and encourage community participation in jointly putting in place a system of solid waste management to ward off the challenges of public health and global warming. For this to be possible, state governments will have to actively empower their urban local governments through financial devolution, greater autonomy in mobilising own resources, e.g., levying user charges to cover costs, reforms in governance, and build their capacity for planning and implementation. Legal changes and notifications will have to be put in place in compliance with the SWM Rules (2016). In addition, the regulatory regime will need to be strengthened and its enforcement ensured. The Government of India will have to provide strategic leadership to nudge the state governments in creating an enabling environment for urban local governments to fulfil the mandate of effective solid waste management.

Sec 1 presents the municipal solid waste (MSW) scenario in India, highlighting the phenomena of rapidly rising volume of municipal solid waste, its changing composition, continued practice of mixing biodegradable waste with dry waste at the source of generation, growing volume of plastic in the waste including the challenge plastic waste poses for recycling and disposal, and the inefficient systems of collection and transportation of the waste. It also documents how the waste pickers together with the *kabadiwalas* in the informal

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1 Aman Luthra, Economic & Political weekly, April 2017

2 "Solid Waste Management Rules, 2016 – Major changes and likely implications", MoEF&CC, spells out the significant differences from MSW (Management and Handling) Rules, 2000. See http://pibphoto.nic.in/documents/rlink/2016/apr/p20164503.pdf

3 Following a Public Interest Litigation filed in 1996 by Almitra Patel against the Union of India regarding management of waste in India's cities [WP(c) 888], the Supreme Court issued an order setting up an Expert Committee to submit a Report on Sustainable Techniques of MSW Management. The recommendations of this Committee formed the basis for the Municipal Solid Waste (Management and Handling) Rules, 2000 which were notified by the Ministry of Environment and Forests, Government of India in 2000.

sector play a major role in the collection of waste and recovery of recyclables in many Indian cities.

Sec 2 presents the status of resource recovery. Recycling offers a route through which usable materials which otherwise might end up as waste, are recovered and reprocessed. It appears that India has a reasonably good record on recycling although the potential is far from realised. For biodegradable waste, a few cities have biomethanation plants which produce manure, while composting facilities are present in more cities although these are heavily underutilised because of lack of demand for compost. This is followed by a review of the state of play of "waste to energy" plants in India which use dry waste for making Refuse Derived Fuel (RDF) and also incineration and gasification plants for electricity generation. What emerges from this review as critical institutional reforms for effective waste management is a regulatory mechanism for setting emission norms for the waste to energy plants and an enforcement capacity to ensure that the norms are adhered to.

Sec 3 highlights the lack of scientific disposal of solid waste at the landfill sites and its cumulative effect on the environment. It identifies the sources of Greenhouse Gas emissions and presents estimates of the emissions from municipal solid waste in a set of selected Indian cities. Sec 4 concludes by presenting a roadmap of sustainable solid waste management, addressing issues of environmental sustainability as well as financial sustainability.

## 2. Municipal Solid Waste Scenario in India

Municipal solid waste is defined to include household waste, commercial and market area waste, slaughter house waste, institutional waste (e.g., from schools, community halls), horticultural waste (from parks and gardens), waste from road sweeping, silt from drainage, and treated biomedical waste (**Chart 1**). Construction and Demolition (C&D) waste used to be defined as part of municipal solid waste until recently, but Solid Waste Management Rules 2016 have taken C&D waste out of the definition and C&D Waste Management Rules 2016 have been separately notified.[4] Until proper systems are put in place for managing C&D waste in compliance with the new Rules, there is danger of neglecting C&D waste in the transition, while the volume of C&D waste is likely to grow rapidly with the increase in construction activity as India gets back to the trajectory of rapid growth.[5]

There are no reliable estimates of municipal solid waste generation in India. The alternative available estimates are presented in **Table 1.** The latest available official estimates of MSW generation from the Central Pollution Control Board and the Ministry of Urban Development, Government of India are for 2014-15 and they place annual generation of MSW at 52 million tonnes. The Report of the Task Force on Waste to Energy of the Planning Commission in 2014 estimates MSW generation at 62 million tonnes in 2013-14. Assuming urban population of 440 million in 2017 (based on projections from United Nations population estimates) and

[4] See Section 4(c) and Section 15(s) of Solid Waste Management Rules 2016

[5] Plastic Waste Management Rules 2016, E-Waste Management Rules 2016, Biomedical Waste Management Rules 2016, and Hazardous and Other Waste Management Rules 2016 are also separately notified by MoEF&CC

per capita daily waste generation of 450 gm, the MSW generated for 2017 comes to 72 million tonnes. If the assumption with respect to per capita daily waste generation is lowered to 400 gm, the estimate of MSW generated for 2017 is lower, i.e., 64 million tonnes. This does not include electronic waste which is estimated at close to 2 million tonnes in 2017 and a major unknown, i.e., Construction and Demolition waste for which the estimates range from a mere 10 million tonnes per annum to an enormously larger volume of 520 million tonnes per annum, with some suggesting that C&D waste is about 30 per cent of the total waste.

**Chart 2** presents Indian cities which are top generators of solid waste in 2016, based on data reported by the cities themselves. The 6 largest metropolitan cities (Delhi, Mumbai, Kolkata, Chennai, Bengaluru, and Hyderabad) generate the maximum volume of solid waste, ranging from 4000 TPD (tonnes per day) in Hyderabad to 9260 TPD in Delhi. Together they account for 21 per cent of the total municipal solid waste generated in all Indian cities and towns, while their share of the total urban population is only 16 per cent. Among the smaller cities with population between 1 million and 5 million in **Chart 2**, Kanpur and Lucknow are the highest waste generators, generating 1500 TPD and 1200 TPD, respectively.

Until recently, most of the municipal waste was collected from the community dustbins or *dhalaos* by the municipal governments. Door to door collection prescribed by the Municipal Solid Waste Rules (2000) was either done through Resident Welfare Associations employing private waste collectors or NGOs or not at all. With Solid Waste Management Rules (2016) placing greater emphasis on door-to-door collection of waste segregated at the source of generation and Swachh Bharat Mission providing funds for infrastructure, many cities are reporting increased coverage of door-to-door collection, although the collection is mostly not of segregated waste and the collection coverage also tends to be overstated.

The Report of the Task Force of the Planning Commission (2014) places the biodegradable component of the total municipal solid waste in India at 51 per cent, which seems to be an underestimate (**Chart 3**). Based on the data available for a few cities, it seems that the biodegradable component would be somewhere between 55 and 60 per cent on an annual basis. As **Chart 4** shows through a comparison across the different income groupings of countries, the biodegradable component of municipal solid waste declines with rise in income; the high income countries have 28 per cent, upper middle income countries 54 per cent, and the lower middle income countries 59 per cent of their municipal solid waste which is biodegradable (World Bank 2012). **Chart 4** shows China's biodegradable waste component to be higher than the average of the group of upper middle income countries to which China belongs. India's biodegradable component, by contrast, is lower than its group of lower middle income countries. The available estimates of biodegradable waste at 55-60 per cent for a few Indian cities would also suggest that perhaps the biodegradable waste component in India is actually higher than the estimate of 51 per cent prepared by the Task Force of the Planning Commission (2014).

The responsibility of ensuring that the biodegradable waste is not mixed with other waste but processed separately to recover compost and/or biogas is therefore larger than what the numbers suggest. Separate decentralised processing of the biodegradable waste reduces the burden of hauling mixed waste to long distances (10 km to 30 km) including to landfill sites where it decomposes over time, resulting in leachate and contamination of groundwater, foul odour, and also emissions of methane which is a potent Green House Gas causing global warming. In actual practice, segregation of wet waste from dry waste at the source of generation in Indian cities is more the exception than the rule. **Table 2** presents data on door-to-door collection and segregation at source for selected cities and towns as reported by the cities and towns themselves.

Learning from the experience of the Municipal Solid Waste (Management and Handling) Rules 2000 for segregation of waste at source, the Solid Waste Management Rules 2016 have gone much further in making segregation of waste compulsory and assigning the responsibility for compulsory segregation into biodegradable, non-biodegradable and domestic hazardous waste (including sanitary waste) to waste generators themselves. This is in line with Article 51 A (g) of the Constitution of India which states "it is the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife". There is also provision for penalty for non-compliance. Surprisingly, the awareness on the part of city residents of the linkage between poor management of solid waste and public health is very low even in the big metropolitan cities. The improvement in outcomes on the ground depends on spreading awareness of this linkage, notifying the rules for individual municipal jurisdictions and then ensuring their enforcement.[6] The involvement of Resident Welfare Associations is crucial for expediting this process.

Information on segregation at source is either not available or not reliable (**Table 2**). The large metropolitan cities show the worst performance. Bengaluru and Pune are the only two large cities with around 50 per cent of the waste segregated at source. In Bengaluru, however, the segregated waste is often mixed with unsegregated waste and dumped at landfill sites due to lack of processing facilities. Among mid-size cities, Indore and Mysore have achieved 90 per cent and 95 per cent segregation at source, respectively and a number of small towns have attained 100 per cent segregation, as reported in **Table 2**. The estimates of door to door collection generally appear to be much higher than what the situation on the ground would suggest. The variation across the cities is also very marked. Ahmedabad shows the maximum door to door collection at 95 per cent, while Delhi is the other extreme at only 39 per cent.

Beginning with the 1990s, cities such as Pune, Rajkot, Pammal, and Mysuru in partnership with NGOs have experimented with organising the waste pickers, offering them segregated waste for collection, providing them better working conditions for sorting dry waste for recyclables, and integrating their contribution to waste management with the formal solid waste management system.

[6] The High Court of Delhi played an important role in setting up a committee on Long-term Action Plan for Solid Waste Management in Delhi in August 2017. The committee in its report submitted to the court, recommended model by-laws. In January 2018, the necessary by-laws were notified by the Lieutenant Governor of Delhi and the three Municipal Corporations of Delhi, New Delhi Municipal Council and the Delhi Cantonment Board are now bound to enforce the laws in the areas of their jurisdiction.

Waste pickers and *kabadiwalas* (small and big waste buyers and aggregators) have traditionally played an important role in solid waste management in Indian cities as they have tried to collect, sort and process recyclable waste in the informal sector. While it is common practice for *kabadiwalas* to collect recyclable waste such as paper, plastic, glass, metal, etc. through door to door collection and sell it to dealers who in turn further segregate and sell it to the recycling industry in bulk, there are also marginalised women and children who pick recyclables from mixed waste dumped at *dhalaos*, streets and also landfill sites where waste is dumped, putting their own health at risk.[7] Not all of the recyclables can be retrieved from the mixed waste, and the waste pickers' collection is typically soiled with biodegradable waste and/or biomedical waste, and for that reason, they can sell this for very little in the market.

Pune has been a pioneer in getting the local communities engaged in segregation of waste at source. Pune's journey in segregating its municipal solid waste began in 1990 by initiatives from SNDT Women's University in organising the waste pickers in a trade union in the first instance and a cooperative society called *SWaCH* subsequently, so as to work with the Pune Municipal Corporation for collecting and recycling waste.[8] As of 2017, 53 per cent of Pune's households are covered by the members of *SWaCH*.

The Pune Municipal Corporation provides the waste-pickers from *SWaCH* with uniforms, equipment, identity cards, health insurance, and also sheds for sorting recyclables from the non-biodegradable waste. Besides what they receive from households for their services, waste-pickers are allowed to sell the recyclables and retain the earnings from the sale. They in turn ensure that the segregated wet waste is either composted in housing societies or delivered daily to the local biomethanation plants, thereby playing an important role in the Corporation's efforts to produce manure and bio-gas, and ultimately electricity, from the wet waste. Pune has shown the direction in which other Indian cities have to move to manage their solid waste in a sustainable manner. Admittedly, these are low-productivity and low-wage jobs and the next generation of waste pickers is aspiring to move to better jobs. But until segregation at source is practiced universally and higher incomes make it possible to mechanise the process of collection, sorting and processing of segregated waste, the informal sector has a very important role to play in solid waste management.

Rajkot Municipal Corporation is another corporation in the country which started a campaign to build community awareness about solid waste management in the 1990s. With the involvement of self-help groups of men and women, segregated waste from the households of the city is collected daily and delivered to processing sites for resource recovery and disposal. Ban on the use of plastic carry-bags and penalty for littering in public places was introduced in Rajkot as early as 2008. Pammal, a small town with population of about 100,000 in the

[7] SWM Rules 2016 do not mandate environmental and occupational health audit for those involved in management and handling waste (Gopal Krishna, Economic & Political Weekly, April 2017)

[8] Dr Laxmi Narayan and Ms Poornima Chikarmane of SNDT Women's University spearheaded a campaign in some localities of Pune for segregation of biodegradable waste from other waste, motivated by the desire to improve the working conditions of the child waste pickers. Since the time saved by the child waste pickers could be spent in attending school, this even encouraged the mothers of these children to step forth to collect segregated scrap from the households directly.

outskirts of Chennai, also started early in 1994 to collect segregated waste and opt for composting and recycling. The transformation of the solid waste management scenario of Rajkot and Pammal has been documented in *Transforming Our Cities* (Ahluwalia, Harper Collins 2013). Mysuru in Karnataka has also made significant progress in door-to-door collection and high segregation of waste at source. Warangal in Telangana won the Clean Cities championship in 2012 as its segregation at source and high resource recovery rate led to reduction in landfilling by up to 40 per cent.

A few small cities have made substantial progress on door to door collection and segregation thanks to a motivational environment provided by the *Swachh Bharat Mission*. Suryapet in Telangana, Gangtok in Sikkim, and Bobbili in Andhra Pradesh are carrying out 100 per cent door to door collection. Tirunelveli in Tamil Nadu, Vengurla in Maharashtra, and Uttarpara-Kotrung in West Bengal have not only attained 100 per cent door-to-door collection but also 100 per cent segregation. In Bobbili, the municipal workers segregate the waste. These towns have gone one step further by composting all their wet waste. In Alappuzha in Kerala, the Municipal Corporation does not collect wet waste; it is processed by residents at their home through composting or bio-gas (CSE 2016).

While a few cities have seriously attempted using waste pickers to collect segregated waste and keep the streams of waste separated for processing down the line so that both resource recovery and the working conditions of the waste pickers, are improved as discussed above, most of the 8000 or so cities and towns of India have still to begin their journey towards segregation at source, door-to-door collection, separate transportation, and integrating the informal sector in the process of solid waste management.

## 3. Resource Recovery

Resource recovery involves use or extraction of discarded materials from waste for reuse so as to defer consumption of virgin resources, mitigate greenhouse effect, and minimise the amount of waste disposed into landfills. Recycling, composting, and energy generation from waste offer alternative possibilities of resource recovery so that waste going into landfills is minimised.

An important instrument of resource recovery is sustainable material management which involves using and reusing materials more productively over their entire life cycle. It calls for emphasis on consuming less and reducing environmental impact of consumption by using and reusing materials in production. While it requires fundamental change in the behaviour and pattern of consumption and production (including packaging), sustainable material management results in augmentation of resources for future use in return. A detailed assessment of a product’s life cycle from extraction to end-of-life helps in better understanding its impact on the environment, thereby enabling more informed decisions for creating new avenues to reduce costs and conserve resources. Extended Producer Responsibility (EPR) and Take-back schemes are examples of focusing on the end-of-use treatment of consumer products and their packaging, and promoting resource recovery by the manufacturers themselves.

Extended Producer Responsibility is a policy tool that makes it mandatory for a producer, partially or completely, to take financial and/or operational responsibility for the disposal of packaging materials, batteries and electronic components, etc. of a consumed product to facilitate its end-of-life management. It shifts the waste management responsibility of products covered under this policy from municipal governments to producers. The producers in turn incorporate the cost of post-consumption product and packaging in the selling price of the product. Solid Waste Management Rules 2016 mandate manufacturers of products using recyclables such as tin, glass, and certain plastics for packaging to provide necessary financial assistance to municipal authorities for establishing waste management systems and/or set up a system to take back the waste generated. Japan provides an excellent example of recycling and extended producer responsibility in waste management (Box 1).

**Box 1: Recycling and Waste Management in Japan**

Between 2006 and 2015, Japan’s GHG emissions from solid waste sector declined by about 18 per cent (UNFCCC 2017). From a peak of 54.8 million tonnes in 2000, Japan brought down its waste generation to 44.9 million tonnes in 2013. Of this 22 per cent was recycled, 75 per cent incinerated, and about 10 per cent was sent to landfills.

There are lessons to be learnt from Japan in its practice of recycling in general and Extended Producer Responsibility in particular. Business operators are required to reduce the generation of container and packaging waste in Japan by cutting the thickness and weight of containers and packaging, charging fees for plastic shopping bags received from the store, and using returnable containers (Containers & Packaging Recycling Act, 1995). They must recycle containers and packaging used (including from imports) in their business operations. Recycling operations are typically outsourced to Corporations designated by the Containers and Packaging Recycling Act. Manufacturers of electrical appliances are responsible to recycle the waste from the home appliances received from retailers, while the cost of collection, transportation and recycling is covered by the consumers (waste generators) themselves (Home Appliance Recycling Act, 1998).

The Automobile Recycling Act of 2002 requires that anyone buying an automobile has to deposit a recycling fee in a fund management corpus of the Japan Automobile Recycling Promotion Centre and has to deliver the automobile back to the dealer when putting the vehicle out of service. The dealer accepts the end-of-life automobile from its owner and provides a certificate of acceptance to the owner. A vehicle dismantler dismantles the automobile for recovery of recyclable parts and metal which are then delivered to automobile manufacturers for reuse.

While incineration looms large in the solid waste management in Japan, and in 2013 there were 1172 decentralised incinerators, they are fitted with state of the art emission control technologies to ensure that there is no adverse impact on the environment.

### *3.1 Recycling of Non-Biodegradable Waste*

Recycling involves recovering and reprocessing usable materials that otherwise might end up as waste. The recovered material can be transformed into useful products that can pre-empt consumption of virgin resources in manufacturing. Use of recycled materials usually requires a fraction of the energy needed to manufacture a product compared with manufacturing the same product with virgin materials. It also helps save energy and associated greenhouse gas emissions across the multiple phases of product lifecycle, e.g., during extraction and manufacturing, and from decomposition. Commonly recyclable materials include paper, cardboard, glass, plastics, metals, etc.

India's rapid growth and urbanisation has resulted in very sharp increase in the consumption of plastic and hence in plastic waste.[9] While India's plastic consumption at 11 kg is still only a tenth of the US and less than a third of China's, according to *PlastIndia* 2015, the projected high growth rates of GDP and continuing rapid urbanisation suggest that India's trajectory of plastic consumption and plastic waste in the years and decades ahead is likely to be sharply upward.

The Central Pollution Control Board estimated in 2013 that about 8 to 9 per cent of the total municipal solid waste in India is plastic waste, of which about 60 per cent is recycled, most of it in the informal sector. A study by National Chemical Laboratory, Pune (2017) estimates that PET recycling in India at 90 per cent is much higher than 72 per cent in Japan, 48 per cent in Europe and 31 per cent in the US. While the recycling rate of plastic in India is considerably higher than the global average of around 15 per cent, there still remains a significant amount of plastic waste rendered unrecyclable mostly due to mixing of different streams of waste, which is either landfilled or ends up clogging drains/sewers or polluting groundwater resources.

Recycling of plastic is not always economically or technically feasible. Composites like roofing sheets and bonded rubberised coir mattresses, for example, are really difficult to recycle when the components are hard to separate. Multi-film plastic sachets used for packaging snack foods and even plastic coated paper cups also pose problems for recycling. This calls for a strategy of building awareness on the differences in recyclability and disposability of different types of plastic to both consumers and producers and also putting a regulatory structure in place which builds in producers' responsibility in recycling (Box 2).

Sec 4(b) of the Plastic Waste Management Rules 2016 explicitly states that only virgin plastic is to be used for storing, carrying, dispensing or packaging food stuff which is ready to eat or drink. Sec 9(3) requires the phase out of non-recyclable multi-layered plastic by March 2018, while Sec 17 requires manufacturers and users of non-recyclable packaging to either pay municipalities for the cost of managing such waste or arrange to take it back and manage its disposal themselves. However, appropriate municipal by-laws have to be notified, and enforcement will be a major challenge.

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[9] Plastics production in India grew at 2.5 times the growth rate of India's GDP during the 1970s, 1980s and 1990s (CPCB 2015).

**Box 2: Halogenated Plastics and Short-life PVC**

Halogenated plastics are halo-carbon polymers used to make pipes, tubes, gloves, flex sheets, etc. Chlorinated plastic, particularly Poly-Vinyl Chloride (PVC), is the most commonly produced halo-plastic owing to its durability and wide range of applications. PVC can be both rigid and flexible and therefore has long-life applications, e.g. in pipes and fittings, cables, cards, roofing membranes, etc., as well as short-life uses such as in making advertisement flexes, bags, etc.

PVC, like any other plastic, does not degrade naturally and releases poisonous dioxins and furans upon combustion, which is why the disposal of PVC waste is a challenging task Several countries, including those in Europe, have imposed ban on soft PVC containing phthalates which are intended for human contact (example toys) for health reasons. Chlorinated plastics are widely used in making gloves, blood bags, etc. owing to their suitability for medical applications However, since incineration is practiced for safe disposal of bio-medical waste; these chlorinated plastics end up being incinerated, there-by releasing toxic gases into the atmosphere. Vinyl Chloride is a known human carcinogen, according to the WHO's International Agency for Research on Cancer (IARC 2012).

Bio-Medical Waste Management Rules 2016 notified by the Government of India, while listing out the duties of a health facility (hospital, blood bank, pathology laboratory, etc.), have ordered phase out of such chlorine containing bags, gloves and other material within two years from the date of notification i.e. 28 March 2016.

Advertisement flexes and bill-boards in India are mostly made of PVC and after fulfilling their marketing tasks, they quickly find their way into trash bins. With no option to recycle, landfill or incineration are their only options for disposal, both posing health hazard. The Department of Housing and Environment of the state of Chhattisgarh has banned manufacturing, storing, importing, selling, transporting and use of short-life PVC and other chlorinated plastics in the state, through a notification in September 2017. This progressive step is worthy of emulation in other states, but enforcement is the key.

An innovative use of soiled and torn thin plastics is in building roads. These thin plastics can double or triple the life and quality of bitumen (tar) roads if they are used in hot-mix plants that supply ready asphalt/bitumen mixes which are spread and compacted for road making. Finely shredded thin-films of plastics are added onto the hot stones which form a baked-on polymer coating over each stone upon getting heat-softened. The bitumen adheres strongly to these coated stones to make the roads more durable especially during rains. Tamil Nadu, Himachal Pradesh and some other states in India are regularly laying plastic roads. In Tamil Nadu, 1400 km of rural tar roads used plastic in 2003-04 alone, consuming about one tonne of waste per kilometre of single-lane road. The Central Pollution Control Board has put out comparative test results and offered guidelines for laying such roads.[10] In 2015, the Central

[10] PROBES/101/2005-06 and PROBES/122/2008-09

Road Research Institute mandated plastic roads for all National Highways up to 50 km from cities that have a population of over half a million.

The recycling rate of paper and paper-based products in India is 27 per cent, much lower than in industrialised countries such as Germany (73 per cent), Sweden (69 per cent), Japan (60 per cent) and USA (49 per cent) (CPPRI 2013), where it is mostly exported to recyclers.[11] According to industry assessments, more than 50 per cent of the business requirements of paper in India are met by imported waste-paper, a third of which is from the US. Recycling of waste paper also results in savings of up to 70 per cent of resources such as energy and water compared to making paper from wood pulp. Even more so than in the case of plastic, lack of segregation and no separate primary collection system for recyclables plays a spoilsport because paper is easily soiled. Proper handling and management of waste paper would save not only foreign exchange but also precious resources such as water and trees, and avoid greenhouse gases that would be emitted in the process of production from virgin material. Thus, for every 1 per cent increase in waste paper recovery, approximately 20 kilotonne of greenhouse gas emissions could be avoided directly on an annual basis, according to a study by the Central Pulp and Paper Research Institute (2013).

It is clear that the method of recovering resources from solid waste depends on the contents of the waste which is not easily discernible particularly when different types of waste are mixed. For example, biodegradable waste can be processed into compost or can be used to generate biogas, while high-calorie, non-recyclable dry waste can be shredded into refuse derived fuel (RDF) for replacing coal in high temperature furnaces (e.g., cement kilns and boilers) or in waste to energy plants.

## *3.2 Biodegradable Waste Processing*

Biodegradable waste is typically of plant or animal origin and can be decomposed by living organisms. Biodegradable waste in the form of food waste from kitchens of households and restaurants, abattoir waste, and horticulture waste forms a major part of municipal solid waste. When the organic matter in the waste decomposes in the presence of oxygen (aerobic decomposition), it breaks down into simpler compounds with the release of carbon dioxide and water, and produces compost which is useful for nourishment of the soil. Alternatively, anaerobic decomposition in the absence of oxygen converts the organic material in the biodegradable waste into methane and liquid slurry, which are useful as biofuel and manure, respectively.

### *3.2.1 Composting*

Decomposition of organic matter in the waste in the presence of oxygen with the help of micro-organisms or worms (such as red wigglers or earthworms) produces compost or vermi-compost, which is a humus rich soil conditioner. City compost from the biodegradable municipal solid waste provides an alternative to farmyard manure (like cow-dung) which has

[11] China used to be the world's largest importer of recyclable waste until recently when it imposed a ban on 'foreign garbage' starting Jan 1, 2018

been valued from time immemorial for its rich microbial content that helps plants to take up soil nutrients. It not only helps restore organic matter in the soil but also provides specific nutrients and reduces the requirement of chemical fertilisers. Application of compost improves water retention capacity of the soil and helps with drought-proofing. The requirement of less water per crop is a welcome feature for a water-stressed future. By making soil porous, compost also makes roots stronger and resistant to pests and decay. India's agricultural soil is severely carbon deficient due to cultivation of the same crop year over year, and excessive use of urea. Use of compost replenishes the organic carbon content of the soil.

Chemical fertilisers when used by themselves pollute surface water with nitrogen runoff because only 20 to 50 per cent of the nitrogen in urea is absorbed by plants. The rest runs off into streams and lakes. The addition of compost or organic manure reduces nitrogen wastage, as its humus absorbs the nitrogen and acts like a slow release sponge. The superiority of integrated plant nutrient supply which combines the use of chemical fertilisers with organic manure was established as far back as 1989 by the Fertiliser Association of India, although not promoted by them until recently under statutory compulsion.

Recognising the importance of organic manure for the balanced nutrition of crops and restoring soil health, the Supreme Court had directed fertiliser companies in 2006 to co-market compost with chemical fertilisers. However, this direction went largely unheeded. The Solid Waste Management Rules 2016 make the co-marketing of compost mandatory. To provide incentive for co-marketing to the fertiliser companies, in February 2016, the Government of India's Department of Fertilisers notified a policy to promote the use of city compost by offering market development assistance of ₹1,500 per tonne on the purchase and distribution of city-compost through the rural outlets of these companies. In 2017, the Market Development Assistance scheme was extended to compost manufacturers on bagged compost in the ratio of 1 bag of compost for 2 bags of chemical fertilisers.[12]

The Market Development Assistance scheme has not worked well because of its administrative complexity. The high volume but low value nature of compost makes it not so attractive for fertiliser marketing companies to promote its use. However, high capital and transport subsidies on chemical fertilisers have made compost a costlier choice, leading to poor demand for compost. A possible solution would be to find a way to make the payment of the fertiliser subsidy to the fertiliser companies conditional on the co-marketing of compost. At the same time, the quality of city-compost suffers from poor segregation levels of waste. The possibility of heavy metal contamination due to the presence of batteries and other similar objects in the mixed waste acts as a psychological deterrent on the demand for compost.

**Table 3** presents the information on installed capacity and operational capacity of compost plants in different states of India. The capacity of composting facilities in many cities is

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[12] Ministry of Agriculture, Government of India is also directed to provide flexibility in Fertiliser Control Order for manufacturing and sale of compost and promote utilisation of compost in agriculture.

under-utilised because fertiliser companies are not lifting the compost from manufacturers, reflecting low consumption demand on account of uncompetitive price of compost compared with chemical fertilisers and poor quality of the product resulting from the use of mixed waste as feedstock. The number of commercial scale composting plants installed in the country is 95, with a combined capacity to process 2.37 million tonnes of organic waste annually. However, only 14 per cent of the capacity is utilised to produce 0.33 million tonnes of compost annually (34th Report on Implementation of Policy on Promotion of City Compost, Standing Committee on Chemicals and Fertilisers of the 16th Lok Sabha, 2017).

Pune has used mandatory provisions for composting at source and also provided financial incentives through property tax rebate to encourage households and housing societies to compost their biodegradable waste in-house. The demand for city compost can be encouraged by making the fertiliser subsidy conditional on purchasing and supplying compost in the prescribed ratio with chemical fertilisers. At the same time, segregation at source and on-time delivery of biodegradable waste for composting will guarantee that the compost is of high quality. There is also need for spreading awareness among farmers about the benefits of supplementing chemical fertilisers with organic compost, which include better water retention in soil, and low tillage and weeding requirement. Societies must also be trained for preparing compost from kitchen waste and using it for in house gardens.

### *3.2.2 Biomethanation*

A technically more advanced method for bio-chemical conversion of biodegradable waste is anaerobic decomposition or biomethanation. With the action of microbes in the absence of oxygen, the organic matter is broken down with the release of biogas which contains methane. The gas can be used in place of conventional fuels like LPG or CNG. It can also be concentrated and bottled into Compressed Biogas (CBG) which in turn can be converted into electricity with the use of generators yielding 30 per cent electricity conversion efficiency. However, almost 70 per cent of the energy is lost as heat in the process of conversion. A by-product of biomethanation is slurry which is an excellent liquid manure for agriculture. Biomethanation therefore not only produces energy but also delivers nutrients for soil.

As in the case of composting, biomethanation can also be practiced locally at small scale or at large centralised plants. Several small-scale biomethanation plants (0.5 TPD to 10 TPD) have been installed in a number of Indian cities like Pune, Bengaluru, Mumbai, Delhi, Coimbatore, Matheran, Vadodara and Nasik. These plants produce electricity from biogas, which is used to run streetlights in the neighbourhood. Pune leads the pack with 25 plants of 5 TPD capacity (except two of 3 TDP capacity) spread across the city to process 121 TPD of biodegradable waste (with 80 per cent capacity utilisation). Altogether these decentralised plants process about 10 per cent of the city's biodegradable waste as of 2017. Pune Municipal Corporation provides 600 square meters of land, and 5000 litres per day water and electricity on site for free to each plant. Bengaluru followed the same model of decentralised biomethanation and set up 15 biomethanation plants in the city but hardly any of them are in operation, mainly due to poor segregation of waste.

For efficient operation, feedstock waste must be meticulously segregated and delivered in time to biomethanation plants. Poor segregation levels and inferior quality of feedstock keeps the plants from running at their full capacity. Frequent break-downs result from the presence of non-biodegradable materials in feedstock waste. The processing therefore takes much longer as secondary sorting is carried out at the plant. The resulting odour generates resistance from residents of the neighbourhood where the plant is located. Absence of strict adherence to standard operating procedures and regular maintenance of the plants has also resulted in frequent breakdowns of operations. Systems for recovery of liquid slurry or manure have also not always been in place, resulting in lack of cooperation from the local community. These have been some of the challenges faced by biomethanation plants in Pune.

**Table 4** lists the medium and large scale biomethanation plants that have been set up in recent years. A 30 TPD biomethanation plant setup at the *Koyambedu* Wholesale Vegetable Market in Chennai is a good example of waste processing and energy recovery facility at the point of waste generation itself. The plant was set up in 2006 under the UN Development Program, with technical support from Central Leather Research Institute, Chennai. Even though high-end technology was deployed, the plant has been facing multiple downtimes owing to operation and maintenance issues. More recently, a private company has been contracted by the Chennai Metropolitan Development Authority to operate and maintain the plant (NIUA 2015).

A medium-scale biomethanation plant of 300 TPD that generates bio-CNG has been set up under an agreement between Pune Municipal Corporation and a Pune based private company, with a concession period of 30 years and a tipping fee of Rs 360 per tonne to the concessionaire. Its operations are split between a crushing unit at Baner within the city and a digester unit at Talegaon, 35 km away, which imposes an additional cost for transportation. The biodegradable waste is delivered at Baner by the Corporation and the crushed organic material is transported to Talegaon for the production of biogas by the second unit which is currently working well below its capacity. Using anaerobic digestion to first produce biogas and organic manure, the plant is designed to refine the biogas to higher standards. The gas is compressed and bottled into cylinders and is being sold as industrial fuel. It can also be used as an alternative fuel for vehicles operating on natural gas, including city buses, as demonstrated earlier by the company.

As of 2017, the bio-CNG plant in Pune processes only a modest 75 TPD of biodegradable waste sourced from hotels and restaurants. The split operation with a distance of 35 km between the two locations impinges on the economic cost of operations. The steep decline in the price of natural gas in recent years has also adversely affected the financial calculations for this medium-scale biomethanation plant. The same company owns and operates another plant in Bengaluru on similar lines, but even there the plant is under-utilised since inception; most of the gas generated is being flared owing to lack of effective demand.

Solapur, a city with 9.5 lakh residents, in Maharashtra has set up India’s largest biomethanation plant with a capacity to process 400 tonnes of waste every day. The plant reportedly generates 3 MW of electricity and 60 to 80 TPD of organic manure.

### 3.3 Dry Waste Processing

Refuse Derived Fuel, incineration and gasification are three principal ways in which combustible dry solid waste can be processed to generate energy. It is important to note that solid waste is neither the most efficient nor the most cost effective way of generating energy. Waste to Energy plants have to be seen as elements of an integrated solid waste management system with due precautions to maintain emission norms.

#### 3.3.1 Refuse Derived Fuel (RDF)

Waste other than biodegradable, which is non-recyclable and non-hazardous in nature but possesses high calorific value can be used for energy recovery through the process of combustion. To increase the energy output, the waste is shredded, dried and then compressed into pellets or briquettes, called Refuse Derived Fuel (RDF). These can be used in many industries in place of coal for heat generation. However, the temperature of the furnace should be maintained strictly at 1000 °C or above so that toxic air pollutants such as dioxins and furans are not released upon the combustion of RDF. **Table 5** provides the list of RDF plants in India together with their installed capacity and capacity utilisation.

Solid Waste Management Rules (2016) mandate all industries located within 100 km distance from an RDF plant to replace 5 per cent of their fuel consumption with RDF. The Rules are actually observed more in the breach as RDF utilisation has not picked up after the promulgation of the Rules. As with compost, RDF makers find it difficult to market their product, owing to poor demand from industrial units. Significant cost is incurred on segregating mixed stream of incoming waste before processing it, which brings the overall cost of producing, storing and transporting RDF close to the price of conventional fuel in India and sometimes even higher. This, along with additional bottlenecks of RDF management, e.g. high volume and excess residual ash, makes the fuel undesirable for the consumer.

#### 3.3.2 Incineration

Mass incineration or burning of mixed waste without much pre-processing is a widely practiced method in India which reduces volume and generates heat energy. This process risks the release of toxic gases into the atmosphere especially when the feedstock waste includes heavy-metallic substances, PVC and other halogenated compounds. Presence of wet waste and inert materials like soil and debris also reduces the calorific value of the feedstock, thus dropping the furnace temperature below the required 1000 °C. When auxiliary fuel is used to raise the furnace temperature, it reduces the net efficiency of energy generation from the waste, besides straining the financial viability of such plants. The National Green Tribunal has banned mass incineration of unsegregated municipal solid waste in India since December 2016 although enforcement remains a challenge.

A more refined process of thermally treating such stream of waste is sometimes referred to as controlled combustion where the feedstock waste is segregated from undesirable material and dried (similar to what is done for making RDF) to increase its energy content, and then finally fed into a furnace where it gets incinerated. The heat energy generated is used in a steam-turbine engine to produce electricity. An integrated plant which has both waste processing and energy generation units is commonly referred to as a waste to energy (WtE) plant.

There is little reliable and accurate information available on the calorific value of the municipal waste in Indian cities. Recognising the importance of energy content of feedstock waste for WtE plants, Rules (2016) specify that waste having calorific value of 1500 Kcal per kg or higher must not be disposed of in landfills but should be used in Waste-to-Energy plants for generating energy. An additional problem arises from the fact that the measurement system itself is very flawed.[13]

All incineration based Waste-to-Energy plants must strictly follow the emission norms and have pollution control filters installed to regulate the release of harmful gases into the atmosphere. The emission norms have been made more stringent under Rules (2016) requiring that PM 2.5 emissions from the Waste-to-Energy plants be reduced to 50 ppm compared to 150 ppm under Rules (2000). There is need for real-time monitoring and open access to emissions data to ensure enforcement of the norms. Both the Central Pollution Control Board and the National Green Tribunal have been working towards these goals. But if the testing and regulatory framework is not considerably strengthened, such plants will end up converting solid waste into air pollution and leaving a larger carbon footprint.

**Table 6** presents information on Waste-to-Energy plants which are operational in India. A waste to energy plant based on incineration of unsegregated municipal solid waste at Okhla, South Delhi, processes 1950 tonnes of municipal solid waste per day to feed into its boilers and produces 16 MW of electricity and 30 per cent of the total waste as residual ash and char (which is dumped at the Okhla landfill site). Since its inception in January 2012 and until December 2016, the plant was in the news for not complying with the emission norms laid down by the Ministry of Environment (MoEF&CC). The National Green Tribunal (NGT) in its February 2017 order directed the plant operator to *“adopt better technology for segregation of waste before it is put in the furnaces”* and also imposed an environmental compensation fine of Rs. 25 lakh. The plant has been deemed compliant by NGT after several inspections by the Central Pollution Control Board and is in operation, although the residents of surrounding areas continue to press their charges in court of heavy air pollution caused by the plant.

More recently, two additional incineration based Waste-to-Energy plants have been commissioned in Delhi. The 1300 TPD plant at Ghazipur and the 2000 TPD plant at Narela-Bawana started operations in early 2017. They first process unsegregated solid waste into RDF and then feed the RDF into the electricity generation unit with a capacity to produce 12 MW and 24 MW of power, respectively. In the process of making RDF, biodegradable

[13] A one-gram sample of waste in a bomb calorimeter is hardly representative of the calorific value of the waste.

rejects from the two plants are sent to respective composting units for making compost. The pre-processing followed by controlled incineration is designed to improve the combustibility of the feedstock waste, reduce residual ash, and minimise the generation of toxic gases and pollutants. Unsegregated feedstock requires extensive manual intervention and mechanical screening multiple times to make it suitable for RDF. Given the composition of Indian municipal solid waste, the sorting line has to be stopped and operations interrupted every few hours so that the machinery is not damaged. This seriously cripples the operational capacity of these plants relative to their potential.

Since the energy generated by waste to energy plants is deemed renewable by the Ministry of New and Renewable Energy, Solid Waste Management Rules (2016) direct that the Ministry of Power should fix tariffs for the electricity generated by these plants appropriately (usually twice as high as the rate for electricity from conventional sources) and also ensure that the distribution companies compulsorily buy power from these plants, currently at around Rs 7 per unit. This is over and above the viability gap funding which these plants receive as a capital subsidy from the Ministry of New and Renewable Energy.

### *3.3.3 Gasification*

Processes like pyrolysis, gasification and plasma-gasification are conversion technologies that turn high calorie dry waste into useful products such as syngas, ethanol and bio-char, etc. Gasification converts much of the carbon in any material into gaseous form, as the name itself suggests, upon heating in the controlled presence of oxygen. The gas so obtained is called synthesis gas or syngas and has several applications including electricity generation. While gasification takes place at temperatures ranging between 480 °C to 1650 °C, plasma-gasification happens at even higher temperatures (≥ 2760 °C) and its viability is yet to be proven for municipal waste. Pyrolysis, on the other hand, takes place at relatively low temperature (300 °C to 760 °C) but in the absence of oxygen, the product so obtained is liquid fuel, char and gases like carbon monoxide, hydrogen and methane. A few small viable projects are in operation in the country.

The advantage of such plants is that release of toxic pollutants is significantly low compared to incineration, given that the stream of waste is segregated. However, the output of syngas has to be scrubbed before it can be put to use because the gas in its raw form is a mixture of several other gases which must be removed, and scrubbing is a very high cost operation. An advantage of syngas is that like other gases, it can be stored and transported for later use.

As **Table 6** shows, a gasification plant of 300 TPD capacity near Chennai was commissioned in 2016 under public private partnership. A larger 700 TPD gasification Waste-to-Energy plant was set up in Pune in 2011 under public private partnership. The low calorific value of the incoming waste, sub-standard segregation levels and lack of grid connectivity were some of the factors that contributed to financial non-viability of the plant in Pune and forced its closure in 2013. The plant facilities are being used for processing 250 tonnes of mixed municipal solid waste into RDF.[14]

## 4. Unscientific Disposal of Solid Waste

Once the principles of reduction, recycling and resource recovery have been followed in solid waste management in an environment of no mixing of wet waste with dry waste, the residual waste needs to be safely deposited so as to isolate the non-recoverable and other such waste and keep it from adversely impacting the environment.

Sanitary landfill is an engineered pit with a protected bottom and side-liners where unrecoverable, stabilised waste is buried in layers. The waste is compressed to save space and covered with an inert layer, with vents for gases to release and a bottom drainage network to collect leachate for treatment. SWM Rules (2016) clearly specify the kinds of waste that can be landfilled. But unlike countries such as Germany, our landfill rules are observed more in the breach (Box 3).

India has scientifically engineered landfills only for hazardous waste. Other than that, most Indian cities practice open dumping at sites which were originally allocated for developing sanitary landfills. **Table 7** presents a list of all the land that has been allocated for developing landfills. Very often, open dumps at landfill sites in India are loosely referred to as landfills. But the ground reality is that as of March 2018, there is no operational Sanitary Landfill (SLF) in India.

Even industrial waste is often dumped at landfill sites designated for municipal solid waste. This is because of the very high cost of disposing industrial waste in landfills specially designed for industrial and hazardous waste and lack of enforcement capacity to ensure compliance. World Atlas Partnership in its 2014 Report mapped and profiled the 50 biggest dumpsites in the world. This set includes three Indian dumpsites in Mumbai (*Deonar*, 132 ha), Bengaluru (*Mandur*, 35 ha) and Delhi (*Ghazipur*, 30 ha). The Report estimates that a population of approximately 8.6 million living within a distance of 10 km from these three sites is at potential risk of health hazard.

SWM Rules (2016) mandate that "only the non-usable, non-recyclable, non-biodegradable, non-combustible and non-reactive inert waste and pre-processing rejects and residues from waste processing facilities shall go to a sanitary landfill". Schedule I of the Rules describes in detail the engineering specifications and criteria for setting up and operating landfill sites. The criteria relate to the location, quality standard for bottom and side-liners, ground water and ambient air quality standards, and plantation in and around the site. The *Dadumajra* landfill in Chandigarh though developed scientifically, does not receive waste as prescribed in the Solid Waste Management Rules 2016. Since mixed waste is deposited, it leads to leachate and methane gas generation. There is no mechanism for capturing this gas.

[14] Essel Group, press release Jan 2016, Essel Infraprojects Ltd successfully commissions its maiden waste-to-energy plant in Tamil Nadu

**Box 3: Waste Management and Landfilling in Germany**

Municipal solid waste in Germany started to decline after peaking at 52.8 million tonnes in 2002. By 2014, the country generated 50.1 million tonnes of MSW. Germany was among the first in Europe to introduce policies to limit landfilling in the 1990s. Measures included schemes for collecting packaging waste, bio-waste and waste paper, separately. By 2014, the level of recycling was 64 per cent. While 35 per cent of the waste is incinerated, landfilling has been brought down to as low as 1 per cent - one of the lowest in the world (Eurostat, 2016). The requirement of pre-treatment of MSW before it can be landfilled combined with enforcement of regulations such as the introduction of separate collection and producer responsibility, have been strong drivers in diverting MSW away from landfills and towards recycling.

Ban on the landfilling of non-pre-treated MSW in Germany was introduced in two steps using three legislations (1993, 2001 and 2002). The country, in 2006 itself, fulfilled the EU Landfill Directive that calls for all the member states to reduce the amount of biodegradable municipal waste landfilled by prescribed percentage by 2006, 2009 and 2016. The ban on non-pre-treated waste, fully enforced in 2005, has had a huge impact on the amount of MSW recovered and landfilled. In countries with a low landfill share and high recycling rates, waste treatment has a positive impact on greenhouse gas emissions, reducing emissions from the economy as a whole. Between 2005 and 2015, emissions of GHG from solid waste sector in Germany nearly halved to 10.1 million tonnes (UNFCCC 2017). Going forward, Germany has set increased recycling targets for packaging waste materials and directed producer responsibility organisations to better align fees for packaging with their recyclability.

Capping without ventilation for gas is not a solution because it leaves methane and leachate to form for decades within the cosmetically covered heap. The disastrous effects of building on and around a "closed landfill" were demonstrated at Malad in Mumbai where trapped landfill gases seeped sideways through the soil into the basement of the adjoining Mindspace Commercial Complex, wreaking havoc on every possible electronic equipment and causing health hazard for residents nearby.

Scientifically engineered landfills can be upgraded to capture and store methane gas released from any biodegradable component of the waste dumped. The gas so produced can be utilised to generate electricity, similar to conventional biomethanation plants. Such systems require the landfills to be properly sealed so that the gas does not leak into the atmosphere. In India, two such systems were set up, a small pilot at Ghazipur landfill site in Delhi and another at Gorai landfill site in Mumbai, but much of the gas that could have been extracted from the mixed waste had already dissipated into the atmosphere**.** Landfill sites which have reached their capacity are required to be scientifically closed so as to minimise their environmental impact.

Bioremediation is a simple mechanical-biological treatment which aerobically composts organic fraction of mixed waste and offers a low cost solution to reduce the climate impact of landfill sites – the highest GHG generator in the waste sector. It requires aeration of mixed waste in old dumps by formation of wind-rows and spraying microbial culture that rapidly degrades organic matter aerobically, thus ceasing the production of methane and leachate to nearly zero. For proper aeration, the wind-rows are mechanically turned weekly multiple times, which ensures faster degeneration. It has been demonstrated to reduce the volume of waste by up to 40 per cent, after 4 turnings.[15] The potential of methane gas generation is theoretically brought down by 90 per cent, compared to merely dumping an equivalent quantity of waste unprocessed (Bogner et al, 2007). Mechanical-biological methods could also be used in combination in upgrading landfill sites (ISWA 2009).

After bioremediation, the stabilised waste can be screened for recovery of organic manure, recyclables (polymers, metals, etc.) and high-calorie materials (textiles, timber, coir, etc.). The remaining non-compostable, non-recyclable and low-calorie materials (mostly inert) can be used as fillers in building roads. The screened material of high-calorific value can be processed into refuse derived fuel (RDF) for incineration with energy recovery or co-combustion in high temperature industrial furnaces like cement kilns, boilers, etc. It is also relatively low cost, using the already available earth moving equipment with the municipal bodies.[16]

Landfill sites currently maybe the largest GHG emitter in the waste sector but reducing their emissions and subsequent climate impact is relatively easy to achieve. Bioremediation is an excellent interim solution to quickly save on emissions from such sites, while the systems falling earlier in the hierarchy of waste management are improved, i.e. source segregation and resource recovery.

### *4.1 Greenhouse Gas Emissions from Solid Waste Sector*

Greenhouse gases (GHGs) have been a source of growing concern on account of changing climate patterns and extreme weather events throughout the planet. GHGs create a natural blanket around the Earth's atmosphere by preventing some of the sun's heat energy from radiating back into space, thus keeping the earth warm. However, over the last century and a half, human activities have added considerably to GHGs in the atmosphere, and that continues to result in global warming, causing the earth's average temperature to rise and thereby leading to change in climatic patterns.

Solid waste sector is a significant contributor of GHG emissions globally. The Inter-Governmental Panel on Climate Change (IPCC) estimated that post-consumer waste accounted for up to 5 per cent of the total global GHG emissions in 2005 (IPCC 2007). Greenhouse gases are emitted not only while the waste is managed (as during transportation) but also when it is left to decay in dumpsites. A significant amount of embodied emissions is

15 Ahluwalia and Almitra Patel (Indian Express, June 2017), A City Laid Waste.

16 Almitra Patel's YouTube channel, accessible at https://www.youtube.com/channel/UC4i4LO4B8EBGhAjWSefv2GQ

associated with poor waste management, which can be avoided with proper handling, resource recovery and recycling. Waste minimisation at source in all sectors of an economy has considerable downstream GHG reduction potential.

GHG emissions from solid waste disposal on land as reported to UNFCCC by India in 2015-16 increased at the rate of 3.1 per cent per annum between 2000 and 2010, and by 4.6 per cent per annum for China between 2005 and 2012. However, for both the countries, the estimates of emissions from the waste sector do not include emissions from transportation of the waste.

The relationship between waste and GHG is presented below, highlighting the potential benefits of adopting better waste management techniques in combating climate change are also highlighted. Waste management activities generate carbon dioxide ($CO_2$, ~ 50 per cent), methane ($CH_4$, ~ 50 per cent) and nitrous oxide ($N_2O$, < 1 per cent) gas, among others. As per IPCC (2007), the global warming potential of methane and nitrous oxide are 25 times and 298 times higher than that of carbon dioxide over a 100-year period. However, in the short run, i.e. a 20-year horizon, the same gases are 72 times and 289 times stronger than carbon dioxide in global warming potential, respectively. Clearly, the choice of time horizon can have a profound effect on the estimate of climate impact of emissions. If the objective of the study is to analyse the long-term climate impact, 100-year time horizon is optimal (Fuglestveldt et al 2001).

The main channels through which solid waste management affects GHG emissions are listed below:

**(i)** Consumption without regard for resource conservation creates excess demand for extraction and manufacturing of goods from virgin materials, all of which contributes to greenhouse gas emissions in varying amounts at different stages of production and consumption.

**(ii)** Mixing wet waste with dry waste at the source of generation results in several negative downstream effects.

**(iii)** The increased volume of unprocessed mixed waste adds to transport demand which in turn increases fossil fuel consumption for collection and transportation of waste from the source of generation to the landfill sites.

**(iv)** When the mixed waste (sometimes as high as 70%) is dumped at landfill sites, it releases methane gas that is generated from anaerobic decomposition of biodegradable waste present in the waste.

**(v)** Leachate oozing out of decomposing biodegradable matter releases nitrous oxide.

**(vi)** Any act of burning of waste releases carbon dioxide and other harmful gases.

Of all these activities, the International Solid Waste Alliance (2009) estimates that emissions from landfill sites, due to decomposition of biodegradable waste, are the biggest source of GHG emissions from waste sector globally.

### *4.2 Estimating GHG emissions*

IPCC advocates two methods of estimating GHG emissions from solid waste management, i.e., simple mass-balance approach (MBA) (IPCC default method) and the first-order decay method (FOD). In MBA method, it is assumed that all the methane gas from the waste is released in the year of disposal itself. The FOD method, on the other hand, factors in the period of biological degradation. FOD may produce better annual emission estimates, but MBA is useful when calculating the potential reduction in methane gas emission by switching to alternative waste management techniques. Also, it is difficult to get the necessary information and historical data required for FOD estimation so that faithful emission inventories can be projected. For best results, data collection in this sector should take local circumstances into account to the extent possible.

The IPCC default MBA method requires annual solid waste disposal data as input, along with information on composition of waste and the condition of the disposal site (e.g. whether landfill gas is captured or not). The IPCC Guidelines define the default value for most of the data required in estimation. The method produces fairly good estimates only if the amount and composition of waste, as well as the disposal practices remain broadly consistent for considerably long periods. For example, increasing amounts of waste disposed will lead to overestimation, while decreasing amounts will lead to underestimation of annual emissions.[17]

As per the IPCC convention, only methane emission from landfill sites is estimated/ reported, expressed as tonnes of carbon dioxide equivalent. Carbon dioxide emission is considered as biogenic carbon (naturally occurring) and is separately accounted under land use, land-use change and forestry sector (IPCC 2006). The mass balance approach for estimating emissions is based on the following equation:

$$\boldsymbol{Methane\ Emissions}\ \left({}^{kt\ CO_2e}\!/_{yr}\right) = MSWt \times MSWf \times MCF \times DOC \times DOCf \times [(F \times MCR) - R] \times [1 - OF] \times 25$$

where:

MSWt = total mass of waste generated (kilotonne/year);

MSWf = fraction of MSW disposed at landfill sites

MCF = methane correction factor for aerobic decomposition in the year of deposition (= 0.4)

DOC = degradable organic carbon in the year of deposition ($C_{gms}$/$waste_{gms}$, ~0.11)

17 "Good practice guidance and uncertainty management in national greenhouse gas inventories." IPCC (2001).

DOCf = fraction of degradable organic carbon which decomposes (= 0.5)

F = fraction of methane in generated landfill gas (= 0.5)

MCR = methane to carbon molecular weight ratio ($\Rightarrow$ 16/12 = 1.33)

R = methane recovery (kilotonne/year) (no recovery, = 0)

OF = oxidation factor (unmanaged disposal, = 0)

*(*IPCC recommended values given in parenthesis, multiplied by 25 for methane to carbon dioxide global warming potential equivalence conversion)*

In estimating GHG footprint of various sectors of 7 major cities in India, Ramachandra et. al. (2015) used this methodology to derive carbon dioxide equivalent emissions from disposal of solid waste for the year 2009. Based on the above equation, GHG emissions from MSW disposal in landfill sites are calculated for selected Indian cities, shown in **Table 8**. The untreated disposal of mixed municipal solid waste at landfill sites is around 80 per cent for Mumbai and Chennai, 50-60 per cent for Delhi and Bengaluru, and 35 per cent for Pune. This implies that Mumbai emitted 921 kilotonne of $CO_2e$ of GHG gases from its landfill sites in 2016, equal to annual emissions from 196,000 typical passenger vehicles. For Delhi, the estimate is 137,000 cars (based on US EPA assumptions[18]).

## 5. Towards Sustainable Solid Waste Management

The two overwhelming challenges facing urban local governments in putting an effective solid waste management system in place are (i) environmental sustainability, and (ii) financial sustainability.

### *5.1 Environmental Sustainability of Solid Waste Management*

It is very clear that in the process of solid waste management, sustainability cannot be brought in as an adjunct consideration. It must be built into the different elements of the system and their interaction. The adverse impact on the environment for not following a well defined regime of solid waste management emerges clearly from our analysis. In what follows, we recapitulate the consequences of the current practices of managing solid waste and try to quantify their impact on the environment.

Scientific solid waste management can substantially reduce the GHGs arising out of the waste sector. This would require a significant change in the current practice of solid waste handling and management at the source of generation, at one end, and at the disposal site, at the other. The methods/activities listed below would help save greenhouse gases from getting emitted into the atmosphere from the waste sector:

[18] Greenhouse Gas Emissions from a Typical Passenger Vehicle, US EPA 2014, accessible at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100LQ99.pdf

**(i)** Promoting the concept of Reduce and Reuse and thereby decrease consumption and avoid unnecessary GHG emissions.

**(ii)** Recycling waste to help reduce GHG emissions because the energy required to manufacture a product using virgin materials is higher than when using recycled materials (**Table 9**).

**(iii)** Composting organic waste to improve soil carbon content and help substitute chemical fertilisers in agriculture. Compost helps in carbon dioxide sequestration by storing carbon back into the soil. Other benefits of using compost include higher moisture retention capacity of the soil and higher porousness thereby lowering tillage requirement.

**(iv)** Nitrogen fertilisation of soil through the use of urea or chemical fertilisers is a major source of nitrous oxide emissions from the agriculture sector. The gas is also emitted in large quantities during the manufacturing of fertilisers. Excessive application of fertiliser in soils also leads to eutrophication of water bodies because at a time only up to 50 per cent of the nitrogen in urea is absorbed by the plants; the rest runs off with water into streams or lakes. For every tonne of waste that is composted, carbon deposition saves up to 79 kg of $CO_2e$ and fertiliser displacement saves up to 82 kg of $CO_2e$ GHG emissions (Boldrin et al, 2009).

**(v)** Biomethanation or anaerobic decomposition of biodegradable waste harnesses the latent energy in organic matter. It generates biogas which can substitute gaseous fossil fuels like LPG, CNG, etc., and produces slurry which is an excellent organic fertiliser, both of which help in reducing GHG emissions.

**(vi)** Converting non-biodegradable and non-recyclable waste of high calorific value into refuse derived fuel to extract energy. The RDF so produced can either be used directly to substitute fossil fuels like coal in cement kilns or boilers to generate heat or it can be used as feedstock for incineration based waste to energy plants to produce electricity. RDF can also be used in gasifiers (or pyrolysers) to produce syngas which has the potential to replace gaseous fossil fuels or can even be chemically converted into ethanol to substitute or blend liquid fossil fuels like gasoline, etc.

In the case of dry waste, however, recycling should be the priority and RDF/incineration should be the method of last resort once all other recovery options are exhausted.

**(vii)** Depositing unrecoverable carbonic compounds i.e. non-biodegradable and non-recyclable carbon compounds of low calorific value (e.g. lignin), into sanitary landfills to isolate them from the environment.

**(viii)** Bioremediating landfill sites to reclaim the space and also to save on GHG emissions. It is probably the quickest and the most frugal way possible to solve problem of legacy of waste accumulated at dumpsites

Waste prevention, in the first instance, has the potential to dwarf the benefits derived from any other waste management practice; still it typically receives minimal attention and/or effort. Consumer awareness programmes motivating ‘Reduce, Reuse and Recycle’ behaviour should be accentuated and mechanisms such as extended producer responsibility should be pushed. The US Environmental Protection Agency (US EPA, 2009) estimates that about 42 per cent of the total GHG emissions in the US are due to poor management of materials in extraction, processing, manufacturing, packaging, recycling and transportation. Emphasising waste prevention, the Agency estimates that 20-50 megatonne (billion kg) of carbon dioxide equivalent emissions could be saved annually if the country’s packaging requirement is reduced by 25 per cent. In an earlier study, they had found that, generally, the net GHG emissions for a given material are the lowest for source reduction and the highest for landfilling (US EPA 2006). **Table 9** gives the material-specific energy requirement as a percentage of energy required for production from virgin material and associated GHG savings (in $kgCO_2e$) for per tonne of material recycled. As the table shows, recycling paper and steel would require only 50 per cent of the energy required for producing the same though fresh materials.

The contribution of informal sector in recovering and recycling materials, and subsequently saving GHG emissions from the waste sector is considerably high. A 2009 report on the Climate Impact of the Informal Waste Sector in India by Chintan Environment Research and Action Group, a New Delhi based NGO, estimated that scientific management of waste in Delhi alone saves around 962 kilotonne of carbon dioxide equivalent emissions each year.[19] Their calculation was based on only paper, plastic, metal and glass recovery, using material specific emission factors programmed in the US EPA’s Waste Reduction Model (*WARM*[20]). However, the report’s authors note that the figures used in calculation are quite conservative and the actual rate of recycling could be much higher, and *WARM* is therefore likely to underestimate the contribution of the informal sector. In all the major cities of India, waste pickers and *kabadiwalas* together prevent at least 15 per cent of municipal solid waste from going into landfill sites, which would have otherwise cost the Municipal Corporations a large sum in managing (Sharholy 2007).

*SWaCH* Cooperative’s waste pickers in Pune recycled over 50 kilotonne of waste in 2016, directly contributing towards GHG reduction by saving 130 kilotonne of carbon dioxide equivalent emissions. This is equivalent to avoiding consumption of 55,000 kilolitre of fuel or carbon dioxide sequestered by 3.3 million plants grown for ten years. Further the paper-waste sent by *SWaCH’s* waste-pickers for recycling, saved around 350,000 35-feet tall trees from getting cut (*SWaCH* Pune, 2016, based on *WARM*; accounting for various types of waste generated in the city).

Going forward, the city communities and the municipal authorities and elected councillors must all come together to revamp solid waste management with the objective of not only

[19] Cooling Agents, Chintan 2009
[20] https://www.epa.gov/warm

improving public health conditions, but also recovering resources and making the cities more resilient by mitigating the risks associated with human-induced global warming.

### *5.2 Financial Sustainability of Solid Waste Management*

The basic financial problem facing urban local governments in India is that they are financially very dependent on higher level governments for transfers which are neither guaranteed nor predictable. The total municipal revenues in India are just over 1 per cent of GDP in 2012-13, whereas this ratio was 4.5 per cent in Poland, 6 per cent in South Africa and 7.4 per cent in Brazil. Within this very low level of total municipal revenues, their own revenues have been declining and were just a little over 50 per cent of the total revenues in 2012-13.

Urban local governments in India are generally not empowered to mobilise financial resources through raising taxes or levying user charges or unlocking land value. The last, which is potentially very important, is ruled out because the town planning function has typically not been devolved by the state governments to local governments. Even to increase the user charge levy to cover the operation and maintenance cost of a project, they need approval from the state government.

The investment requirement to bridge the urban infrastructure deficit in the solid waste management sector for all cities and towns of India over the 20-year period from 2012 to 2031 was last estimated by the High Powered Expert Committee on Indian Urban Infrastructure and Services (2011). They estimated a total requirement amounting to Rs 70,000 crore (excluding the cost of land) at 2016-17 prices. Although this is only 1.5 per cent of the total investment requirement over the 20 year period for the urban infrastructure sector, the very weak state of municipal finances means that urban local governments will find it very difficult to meet the demands of capital investment. What is more, urban local governments are also not in a position to build a business model with remunerative user charges which would generate enough return to enable the local government to meet its O&M cost and also help in either borrowing in the capital market or attracting private investment as equity in the project.

In a study published in 2006, the World Bank had found that the solid waste management expenditure of urban local bodies of India is only about 15 to 25 per cent of the total municipal revenue expenditure. Of this, collection and transportation accounts for anywhere between 45 and 90 per cent (for large and mid-sized cities with population greater than 5 lakh) and very little is earmarked for processing, treatment and scientific disposal.

Under the *Swachh Bharat Mission* the Government of India has committed to spend Rs 14,620 crore out of a total Mission cost of Rs 62,000 crore over a 5 year period for all of the existing 4,041 statutory towns in the country. The Mission is largely expected to be financed through the budgets of state/urban local governments, amplified by user charges, unlocking land value, and private sector contributions. These are precisely the areas where JNNURM was not able to deliver because there was very little progress on enforcing the conditionality of reforms to strengthen the finances of urban local governments and build a revenue model for projects under implementation. There is no mechanism specified under *Swachh Bharat Mission* which suggests how these sources of financing would become available.

The Mission has also been mostly targeted towards making cities open defecation free, constructing toilets, and building community awareness, and to some extent on collection and transportation without planning or provision for faecal sludge management. While promoting segregation of waste at source and in-house composting of kitchen waste are also objectives of the Mission, resource recovery and safe disposal have not been emphasised.

Solid Waste Management Rules 2016 mandate local authorities to frame by-laws to levy user charges and also impose fines for littering and non-compliance. This would be a useful source of financial empowerment for the cities assuming that the state governments would approve the user charge levy and local authorities will succeed in collecting the same. Needless to say, it is extremely important to place emphasis on cost reduction in waste collection and transportation. However, infrastructure for transportation, processing, and safe disposal of solid waste would call for levels of investments which the municipalities are in no position to make. Given their stringent financial constraints, urban local governments will have to develop financially sustainable models of service delivery and expect to be supported by capital subsidy where necessary. Every step will have to involve considerations of financial sustainability.

The practice of composting of biodegradable waste would pick up only if there is good demand for city compost. Large subsidy on chemical fertilisers such as Urea creates distortions in relative prices and dampens the demand for city compost. The Government's target of cutting the urea consumption to half by 2022 is a step in the right direction but it has to be backed with subsidy reduction on Urea. The co-marketing of compost has not worked. Forcing fertiliser companies to pick up city compost at pre-determined prices and making fertiliser subsidy disbursal conditional on purchase of compost would be the way forward. Ensuring that the city compost is free from heavy-metal contamination and other pollutants (by not using mixed waste) will also help increase the demand for city compost. Farmers' apprehension about the lower productivity of compost vis-a-vis fertilisers should be countered by dissemination of knowledge and field demonstration of the benefits of using compost, (like extension services in the case of agricultural crops).

Decentralised biomethanation seems to be a promising solution through which almost half of a city's solid waste could be processed. Financial sustainability requires that the biogas is used mainly for cooking or bottled into compressed biogas to be used as fuel, and the slurry is collected, dewatered and marketed as organic manure (upon enhancement). Private participation in the development and operation of biomethanation and/or bio-CNG plants can also be encouraged through viability gap funding, especially since these plants offer tremendous saving on transportation and pre-empt GHG emission complications down the chain of solid waste management.

Several municipalities and corporations have gone for processing mixed waste in Waste-to-Energy plants which involves transportation cost for having the waste and high capital cost of the equipment. These have been helped in the past by policy interventions, e.g. viability gap funding and also preferential pricing of the power that is generated. It is extremely important to ensure that emission norms for such plants are not violated. Even when laws are in place, enforcement capacity has to be strengthened through adequate testing facilities and regulatory institutions which have teeth.

Incineration carries the risk of air pollution if the operations are not carried out meticulously. Adding auxiliary fuel to sustain operations takes a toll on the plant's financial viability and it will also add to GHG emissions.

As regards the large accumulated mixed waste at landfill sites which are used as dumpsites, bioremediation provides a low-cost and expedient solution to the problem of the large accumulated mixed waste at landfill sites. Bio-mining further makes it possible to extract resources from the stabilised waste and reuse the same productively, while at the same time releasing space for other uses at the landfill sites. It works both towards financial and environmental sustainability.

**Chart 1: Definition of Municipal Solid Waste**


***Note:*** *Construction and Demolition (C&D) waste is no longer a part of municipal solid waste. C&D Waste Management Rules 2016, Plastic Waste Management Rules 2016, E-Waste Management Rules 2016, Biomedical Waste Management Rules 2016, and Hazardous and Other Waste Management Rules 2016 are separately notified by MoEF&CC*

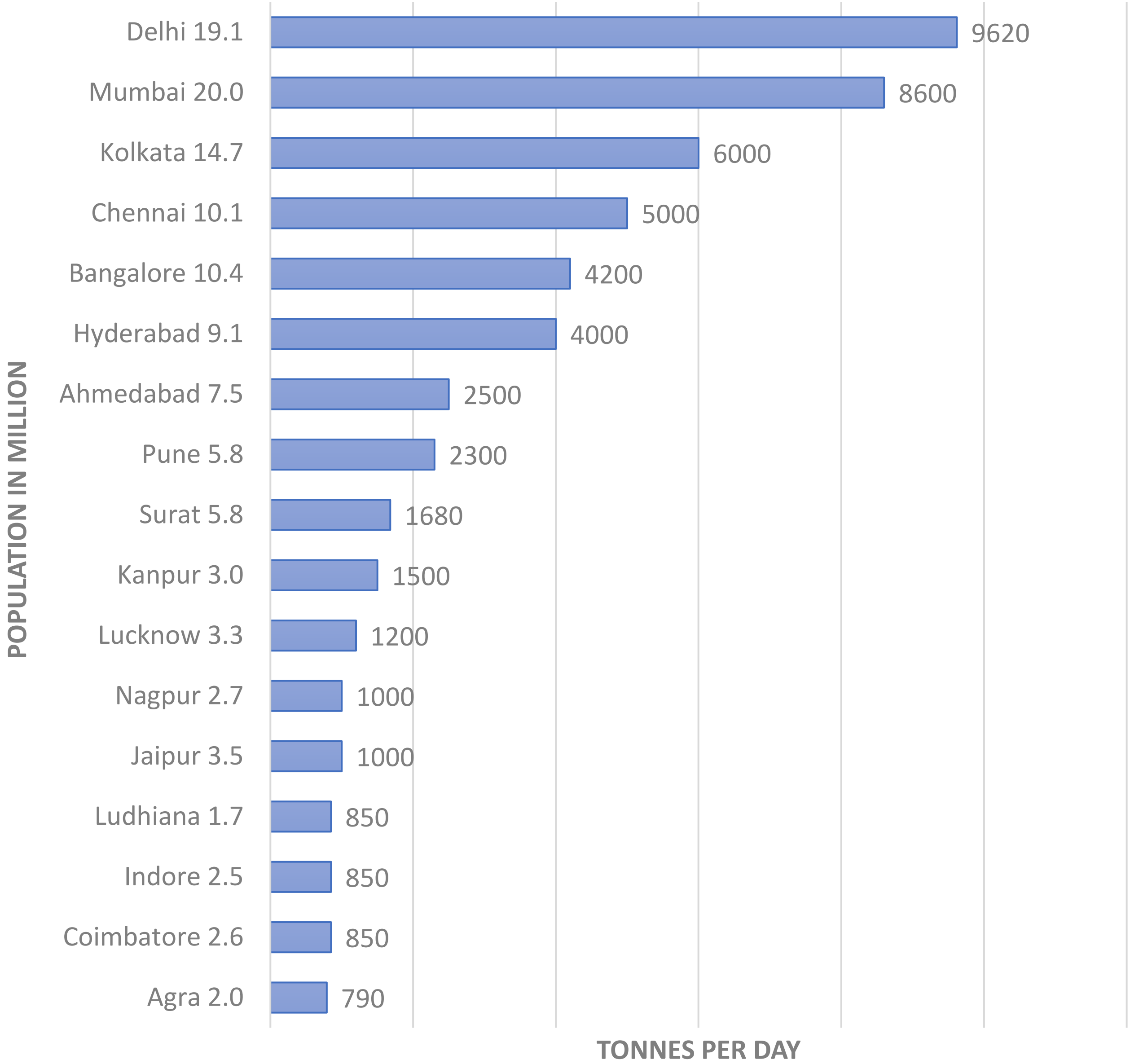
**Table 1: Alternative Estimates for Municipal Solid Waste Generation**

| **Year** | **Source** | **Annual Generation** (million tonnes) |
|---|---|---|
| 2017 | **Our estimate 1**<br>based on 450 gm per capita daily generation and urban population of 440 million* | 72 |
| 2017 | **Our estimate 2**<br>based on 400 gm per capita daily generation and urban population of 440 million* | 64 |
| 2014-15 | **Central Pollution Control Board** | 52 |
| 2014-15 | **Ministry of Urban Development** | 52 |
| 2013-14 | **Task Force on Waste to Energy, Planning Commission** | 62 |

**Based on projections from United Nations estimates*

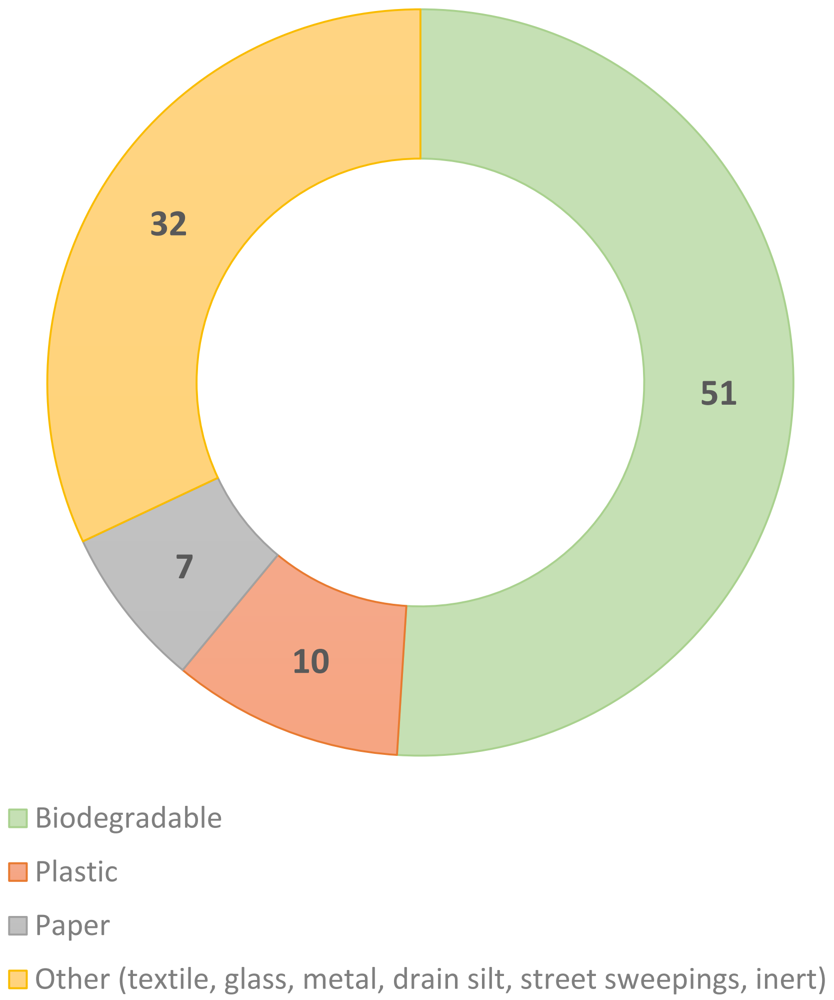
*Source: Central Pollution Control Board, Ministry of Urban Development, and Planning Commission*

**Chart 2: Top MSW Generating Cities/ UAs in India 2016**



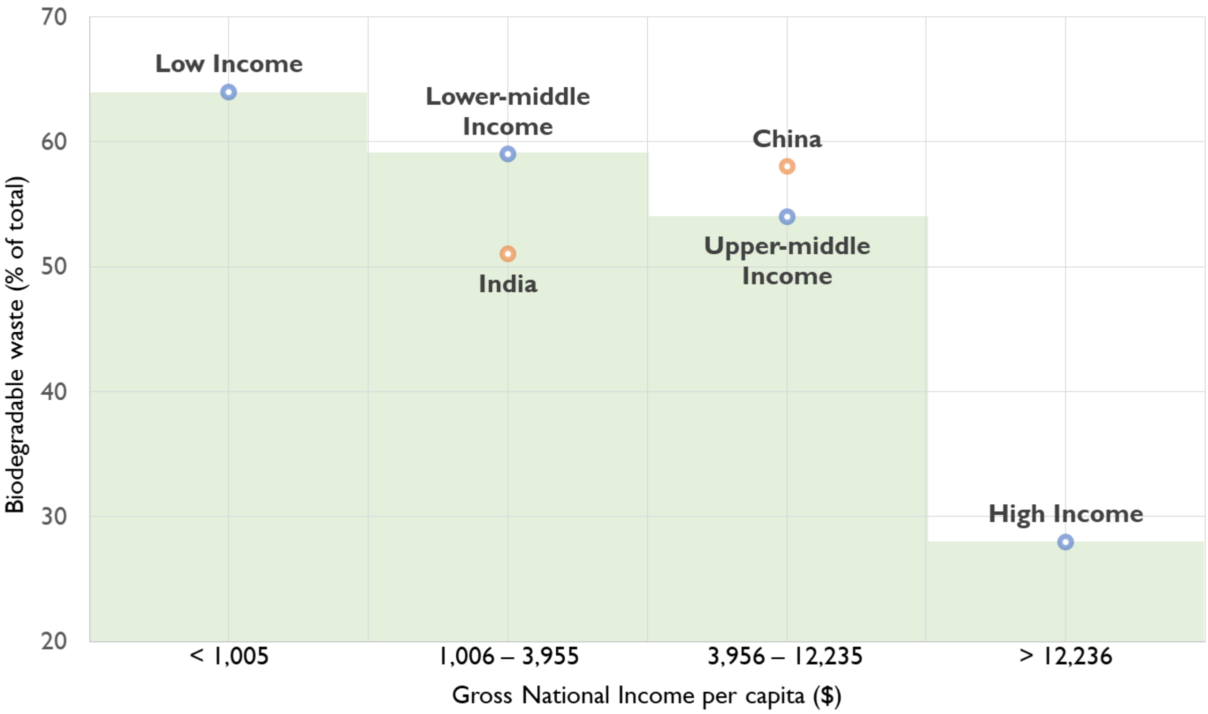

*Source: State Pollution Control Boards, Municipal Corporations, and UN population estimates*

**Chart 3: Composition of Municipal Solid Waste in India (per cent of total)**




*Source: Task Force on Waste to Energy, Planning Commission, 2014*

**Chart 4: Biodegradable Waste Generation: India, China and Other Countries**




***Note:*** *Groups Classified according to The World Bank estimates of 2018 GNI per capita*

*Source: What a Waste, The World Bank, 2012*

**Table 2: Estimates of Collection and Segregation at Source: Municipal Solid Waste Selected Cities**

| City | State | Population (million) | Door-to-door Collection from Households (%) | Segregation at Source (%) |
|---|---|---|---|---|
| **Large Cities** | | | | |
| Mumbai | Maharashtra | 20.0 | 80 | - |
| Delhi | - | 19.1 | 39 | - |
| Bengaluru | Karnataka | 10.4 | 71 | 50 |
| Chennai | Tamil Nadu | 10.0 | 80 | - |
| Hyderabad | Telangana | 9.1 | 73 | - |
| Ahmedabad | Gujarat | 7.5 | 95 | - |
| Surat | Gujarat | 5.8 | 60 | 12 |
| Pune | Maharashtra | 5.8 | 50 | 52 |
| **Mid-size Cities** | | | | |
| Indore | Madhya Pradesh | 2.5 | 90 | 53 |
| Bhopal | Madhya Pradesh | 2.1 | 100 | na |
| Ludhiana | Punjab | 1.7 | 25 | - |
| Chandigarh | - | 1.2 | 95 | - |
| Mysuru | Karnataka | 1.0 | 95 | 55 |
| **Small Cities** | | | | |
| Warangal | Telangana | 0.9 | 90 | na |
| Tirunelveli | Tamil Nadu | 0.5 | 100 | 100 |
| Alappuzha | Kerala | 0.2 | 100 | 76 |
| Suryapet | Telangana | 0.1 | 100 | na |
| Gangtok | Sikkim | 0.1 | 90 | 30 |
| Panaji | Goa | 0.07 | 100 | 90 |

***Note:*** *Large cities imply population greater than 5 million, mid-sized 1 million to 5 million and small cities less than 1 million. Data for Kolkata are unavailable.*

*Source: Municipal Bodies of different cities/ miscellaneous*

**Table 3: Installed and Operational Capacity of Compost Plants in India by State**

| State | Number of Plants | Installed Capacity (tonnes/year) | Operational Capacity (%) |
|---|---|---|---|
| A&N Islands | 1 | 90 | - |
| Andhra Pradesh | 2 | 2,400 | 20.0 |
| Assam | 1 | 15,000 | 15.0 |
| Chhattisgarh | 1 | 1,200 | 20.0 |
| Daman & Diu | 1 | 4,050 | - |
| Delhi | 4 | 1,68,000 | 16.1 |
| Goa | 1 | 1,200 | 20.0 |
| Gujarat | 15 | 1,74,300 | 19.5 |
| Haryana | 4 | 18,600 | 15.3 |
| Karnataka | 18 | 4,73,400 | 10.1 |
| Kerala | 3 | 1,56,000 | 20.0 |
| Madhya Pradesh | 1 | 36,000 | 15.0 |
| Maharashtra | 13 | 4,88,400 | 12.5 |
| Punjab | 2 | 19,200 | 15.0 |
| Rajasthan | 1 | 1,80,000 | 15.0 |
| Tamil Nadu | 9 | 67,680 | 15.8 |
| Telangana | 5 | 1,92,000 | 15.0 |
| Tripura | 1 | 75,000 | 6.0 |
| Uttar Pradesh | 7 | 1,24,560 | 15.2 |
| West Bengal | 5 | 1,70,400 | 15.0 |
| **Total** | **95** | **23,67,480** | 14.0 |

*Source: 34th Report on Implementation of Policy on Promotion of City Compost, Standing Committee on Chemicals and Fertilisers of the 16th Lok Sabha (2017)*

**Table 4: Medium and Large-scale Biomethanation Plants in India**

| City | Developer | Installed Capacity (TPD) | Output |
|---|---|---|---|
| Pune | Nobel Exchange | 300* | Bio-CNG: 4 TPD<br>Manure: 7.5 TPD |
| Bengaluru | Nobel Exchange | 250# | Bio-CNG: - TPD<br>Manure: 25 TPD |
| Solapur | Organic Recyclers | 400# | Electricity: 3 MW<br>Manure: 60 TPD |
| Chennai | Ramky | 30 | Electricity: 0.26 MW<br>Manure: 3 TPD |

** Operational capacity as of 2017 is 25%*
*# Currently operational capacity not available*

*Source: Municipal Bodies of different cities/ miscellaneous*

**Table 5: RDF Plants in Operation in India**

| Location | Developer | Capacity (TPD) | RDF (TPD) |
|---|---|---|---|
| Kochi | Kochi MC | 400 | 100 |
| Jaipur | Vikram Cements | 500 | 150 |
| Surat | Hanjer | 500 | 125 |
| Chandigarh | Jaypee | 500 | 300 |
| Pune | Rochem | 400 | 250 |
| Navi Mumbai | Pyrocrat | 300 | - |
| Bengaluru | MSGP | 500 | - |
| Bengaluru | KCDC | 200 | - |

*Source: Municipal Bodies of different cities/ miscellaneous*

**Table 6: Waste-to-Energy Plants in Operation in India**

| Location | Developer | Capacity (TPD) | Electricity Generation (MW) |
|---|---|---|---|
| Delhi – Okhla | Jindal | 1,950 | 16.0 |
| Delhi – Ghazipur | IL&FS | 1,300 | 14.0 |
| Delhi – Bawana | Ramky | 2,000 | 24.0 |
| Hyderabad | Ramky | 2,400 | 20.0 |
| Hyderabad | IL&FS | 1,000 | 11.0 |
| Chennai | Essel | 300 | 2.9 |
| Jabalpur (MP) | Essel | 600 | 9 |
| Shimla | Elephant Energy | 70 | 1.75 |

*Source: Municipal Bodies of different cities/ miscellaneous*

**Table 7: Land Allocated for Developing Landfills**

| City | Number of known landfills sites | Area (acre) |
|---|---|---|
| Chennai | 2 | 1150.3 |
| Coimbatore | 2 | 721.5 |
| Surat | 1 | 494.2 |
| Mumbai | 3 | 345.9 |
| Hyderabad | 1 | 300.2 |
| Ahmedabad | 1 | 207.6 |
| Delhi | 3 | 164.1 |
| Jabalpur | 1 | 150.7 |
| Indore | 1 | 147.0 |
| Madurai | 1 | 120.1 |
| Bengaluru | 2 | 100.6 |
| Vishakhapatnam | 1 | 100.1 |
| Ludhiana | 1 | 99.8 |
| Nasik | 1 | 85.0 |
| Jaipur | 3 | 77.6 |
| Srinagar | 1 | 75.1 |
| Kanpur | 1 | 61.0 |
| Kolkata | 1 | 61.0 |
| Chandigarh | 1 | 44.5 |
| Ranchi | 1 | 37.1 |
| Raipur | 1 | 36.1 |
| Meerut | 2 | 35.1 |
| Guwahati | 1 | 32.6 |
| Thiruvananthapuram | 1 | 30.0 |
| Vadodara | 1 | 20.0 |
| Dehradun | 1 | 11.1 |
| Jamshedpur | 2 | 10.1 |
| Faridabad | 3 | 5.9 |
| Asansol | 1 | 4.9 |
| Varanasi | 1 | 4.9 |
| Agra | 1 | 3.7 |
| Lucknow | 1 | 3.5 |
| Rajkot | 2 | 3.0 |
| Shimla | 1 | 1.5 |

*Source: Central Pollution Control Board, 2011*

**Table 8: Estimated City-wise CO2e Emissions from Landfill Sites in 2016**

| | Total MSW (tonne/day) | MSW dumped | CO2e emission (tonne/day) | CO2e emission (kilotonne/yr) | Equivalence to passenger vehicles (thousands, /yr)* |
|---|---|---|---|---|---|
| **Delhi** | 9,620 | 50% | 1,764 | 643.7 | 137 |
| **Mumbai** | 8,600 | 80% | 2,523 | 920.8 | 196 |
| **Chennai** | 5,000 | 80% | 1,467 | 535.3 | 114 |
| **Bengaluru** | 4,200 | 60% | 924 | 337.3 | 72 |
| **Pune** | 1,600 | 35% | 205 | 74.9 | 16 |
| **Indore** | 700 | 60% | 154 | 56.2 | 12 |
| **Chandigarh** | 450 | 60% | 99 | 36.1 | 8 |

***** *Assuming mileage of 9.2 kilometre per litre and 18,350 kilometre driven in a year, a typical passenger vehicle would emit 1 kilotonne of $CO_2e$ GHG after driving 3,900 thousand kilometre, i.e. 10 times the distance to moon!*

**Table 9: GHG and Energy savings from materials recycled in USA**

| | kg$CO_2$e saved per tonne of material recycled | Energy requirement as a per cent of virgin production |
|---|---|---|
| **Paper** | 838 - 937 | 50 |
| **Aluminium** | 4079 | 10 |
| **Steel** | 540 | 50 |
| **Glass** | 88 | - |
| **Plastic** | 0 - 507 | - |

*Source: US Environment Protection Agency, 2006*

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