Analysis of Solid Waste in India with emphasis on Waste Segregation, Waste to energy and Waste to Compost

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Abstract : In India, the increase in Solid Waste has largely attributed to the exponential population growth; the population being nearly 1.3 billion is rendering about 0.15 million metric tonnes of Solid Waste every day and this waste can potentially occupy 0.235 Cubic kilometers of space each day if left untreated. Further, India is one among the top ten countries with respect to Solid Waste Generation. Solid Waste is contaminating air, water and land resources all over India. The uncontrolled and lack of engineered systems for dumping solid waste has polluted surface and ground water, only to increase diseases to inhabitants in the vicinity and hamper aquatic ecosystem. Several options are available in Integrated Solid Waste Management to make optimal use of Solid Waste to recover usable entities, as well as to produce energy and composts. India actually has a potential to generate 5609MWeq of power from Waste. The present study is focused on current scenario of Waste Management in India and the possible remedies to counter the problem of Solid Waste. The present study is emphasized on drawbacks of the existing practices in Solid Waste Management and remedies for improvising and upgrading the Solid Waste Management Systems.

Keywords: Solid waste, management, energy, recycling, biodegradable

1. Introduction

The enormous quantity of Solid Waste Generated is a prime factor which is posing challenges in managing solid waste, apart from this, the challenge lies in the fact that the physical and chemical composition of Solid Waste is unpredictable and the waste is not being segregated at the source which leads to a complicated mixture to deal with. There exists no single universal method to treat all kinds of waste together; each category of waste calls for a different technology for treatment. The current Solid Waste Management system lags behind due to socio-economic, political and administrative issues of Urban Local Bodies. Proper Solid Waste Management is essential to lower the impact of menace accompanied with Waste. The following sections describe the basics of Solid Waste and its management in brief.

1.1 Fundamentals of Solid Waste

"Solid waste" means and includes solid or semi-solid domestic waste, sanitary waste, commercial waste, institutional waste, catering and market waste and other non-residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture and dairy waste, treated bio-medical waste excluding industrial waste, bio-medical waste and e-waste, battery waste, radio-active waste generated in the area under the local authorities [1].

1.2 Types of Solid Waste

There are several bases for categorizing the waste and the simple classifications are: (i) Dry Waste and Wet Waste depending on the moisture content, (ii) Biodegradable and Non-biodegradable Wastes depending on the degradability, (iii) Combustible and Non-Combustible Wastes depending on the ignitability. Apart from this, the wastes are also classified on the basis of source such as industrial waste, agricultural waste, hazardous waste and biomedical waste. Of all the wastes, the Municipal Solid Waste (MSW) which covers the categories specified in (i), (ii) and (iii) are of greater concern in all Municipalities/Urban Local Bodies [2]. The detailed classification of solid waste along with domain of Municipal Solid Waste is represented in Fig.1.

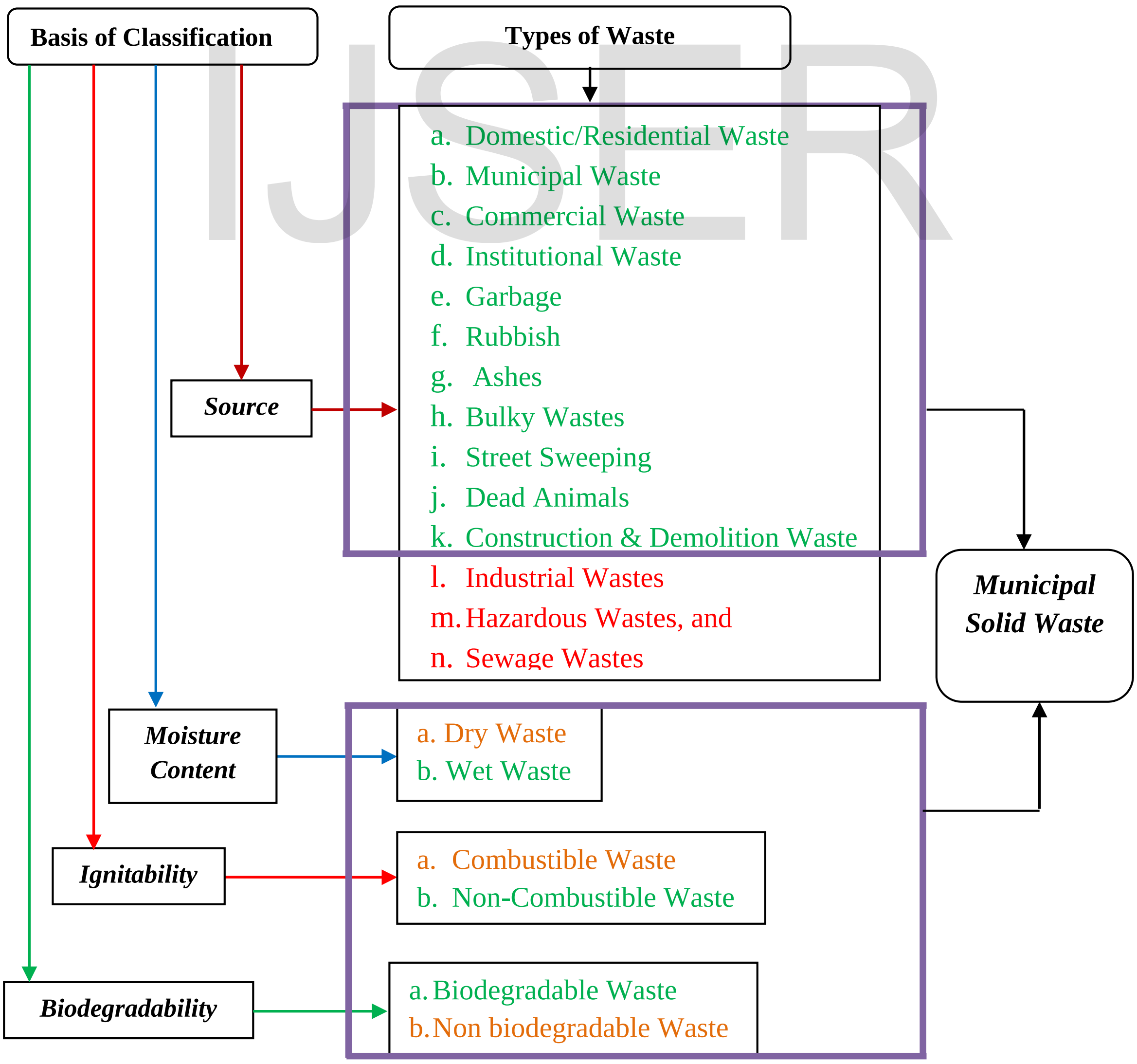

Fig. 1 Classification of Solid Waste and Domain of Municipal Solid Waste

1.3 Critical Parameters for Solid Waste Generation

There are several parameters which affect the quantity of solid waste generation, of which population, standard of living and rate of industrialization are the critical parameters. The Solid Waste generated at any point of time will be directly proportional to population of the region. The same is mathematically expressed as $Q(SW) \propto P(t)$, where Q (SW) and P(t) represent Quantity of Solid Waste and Population respectively. Further, we can incorporate the constant of proportionality and rewrite the equation as $Q(SW) = kP(t)$, where 'k' is the per capita waste generation rate which ranges from 0.10 to 0.60 kg/capita/day and *k* depends on complex factors like standard of living, public attitude, awareness, enforcement of legislations. In general, higher standard of living is expected to increase the value of 'k' due to the fact that the luxurious population will have larger resources available at their disposal. Public attitude and awareness on impact of Solid Waste can decrease the value of 'k' significantly provided the municipality focuses its efforts on Information, Education and Communication (IEC) activities which can lead to capacity building but the transformation of this kind takes years of continual and conscious effort from the municipality and the general public. Strict and stringent enforcement of legislation by levying heavier penalties to the illegal actions with regard to solid waste can substantially reduce the waste generation in industries.

2. Solid Waste Management

Solid Waste Management refers to the iterations involved in (i) collection, (ii) segregation, (iii) transport, (iv) processing, (v) storage, (vi) recycling & recovery and disposal of residual waste after steps (i) to (vi) in an engineering landfill without posing threat to natural resources like air, surface & ground water and land.

2.1 Integrated Solid Waste Management System

In the recent times, many of the developed countries has started to adopt Integrated Solid Waste Management System which is focused on minimizing the waste generation at source itself and targets at lowering the quantity of waste to be disposed in landfills.

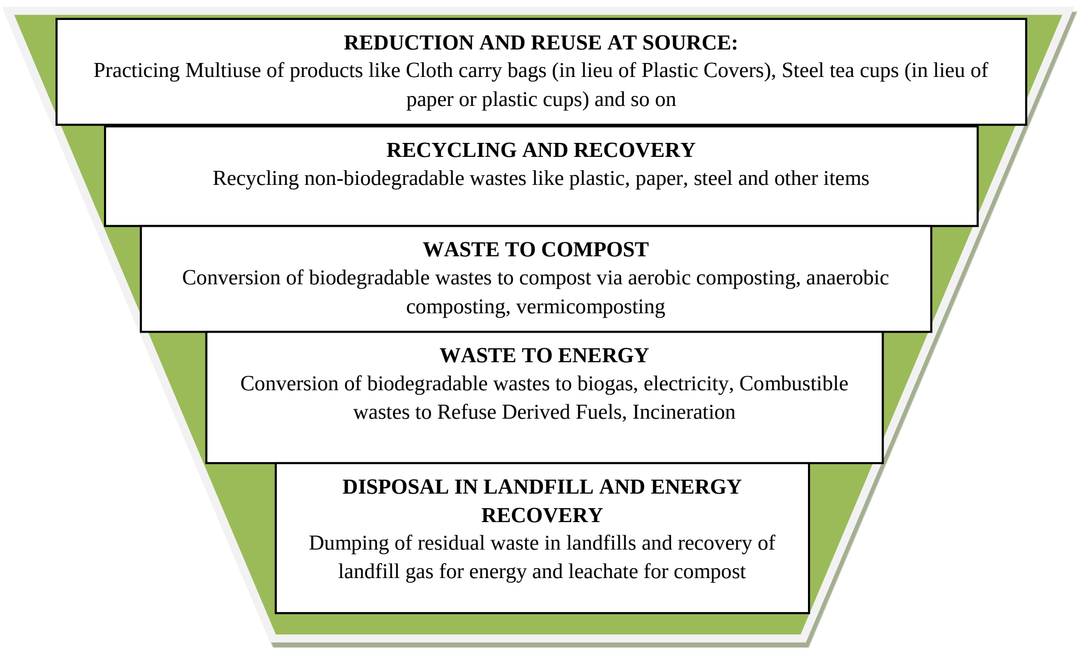

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Fig. 2 Value additions in Integrated Solid Waste Management System

The efficiency of Solid Waste Management system depends on several factors such as door to door collection, frequency of collection, recycling facilities, technologies adopted for segregation of waste, availability of space for processing the waste and distance between the Solid Waste Management Plant to the point of generation of waste .i.e. source; any of the factors mentioned above can be the weak links in the chain of Solid Waste Management.; defects in one link can affect the whole chain, indeed the whole nation and the whole world at large. It is essential to take all preventive measures to avoid generation of waste, try to use the materials till the usage life cycle is completed; reuse the materials as much as they can be, transforming waste to compost and energy. In a way or the other it is prudent to minimize the residual waste to be disposed, which is illustrated in Fig. 2.

2.2 Composition and characteristics of Municipal Solid Waste in India

In order to design a system to manage Solid Waste, it is essential to be aware of the composition. The composition of Solid Waste, in particular Municipal Solid Waste is highly fluctuating in nature. The composition of MSW is quite a complex factor to assess as it varies empirically with respect to region and season. However, several studies in the past have revealed that the biodegradables have increased in the recent times and nearly 50% of the waste is biodegradable. Table 1 illustrates the variation in composition of Municipal Solid Waste in the last two decades.

Table 1 Variation of MSW Composition in India in last two decades

Year	**Composition (%)**							
	Biodegradables	Paper	Plastic/ Rubber	Metal	Glass	Rags	Other	Inerts
1996	42.21	3.63	0.60	0.49	0.60	--	--	45.13
2005	47.43	8.13	9.22	0.50	1.01	4.49	4.02	25.20
2011	52.32	13.8	7.89	1.49	0.93	1.00	--	22.57
	[**Source:** Zhu., D. et.al, 2008 (3), Sunil Kumar eta al, 2017 (4)]							

From the table it can be observed that there is nearly an increase in percentage of biodegradables by an increment of 5% from 1996 to 2005 and from 2005 to 2011. The biodegradable wastes can easily assimilate in to nature if handled properly but open dumping of these wastes can lead to epidemic.

The non-biodegradable wastes can be recycled and recovered easily, however the wastes will contain moisture as segregation will not be done at source most of the time. The wastes can be recovered by means of drying. Recycling is economical and an ecofriendly process; recycling of paper and plastic have been the proven technologies and are being practiced all over the world. Recycling of paper actually solves lot of trees. Waste plastics can be melted to manufacture a Petrol equivalent fuel; plastics can also be blended with bitumen in construction of Roads. Recycling and recovery actually decreases the embodied energy associated with production of materials afresh.

Thus, half the quantity of total waste generated can be used for value addition through composting and biogas generation; the other half can be recovered effectively to accomplish and effective waste management. In order to achieve the objective of economical and efficient waste management, it is essential to segregate the waste at source to reduce the time, labour and burden associated with segregating the waste at the processing facility. Most of the time the processing facilities get overloaded with mixed waste and due limitations of labour, the mixed waste get ended in landfill with recycling and recovery. The importance of segregation is detailed in Section 2.3.

2.3 Importance of waste segregation

Many scientific processes require unification to get a desirable outcome, in contrast Waste Management requires exactly opposite of unification to yield a fruitful result. Segregation plays a key role in Solid Waste Management be it at the source or at the processing facility; segregation of waste to more and more specific categories paves way for handling each category of waste separately.

2.4 Status of Waste Management in India

In India the segregation occurs in two extremes i.e in few areas educated people segregate the waste, store it in different bins and handover the same to municipal workers but the vehicle allotted for collection of waste will not have partition as a result of which the municipal person collects the waste and dumps the segregated wastes together in the trolley of the vehicle. In few other areas, the lack of awareness on segregation the waste is not segregated at all. Table 3 indicates the status of Waste Management in India. It is observed that waste segregation at source is effectively practiced only in 5 States out of 29 and this has affected the waste treated which is as low as 28%. Segregation of waste at sources ensures some monetary returns through sale of plastics, paper & other recyclables and eliminates the costs involved in transporting the mixed waste there by reducing the cost of labour, quantity of untreated waste dumped in landfills by several folds.

Door to Door Collection is still pending in 11 states and such states which are deprived of door to door collection hamper their land areas as open dumping of solid waste becomes an inevitable choice.

There exists a lot of scope for energy generation and composting through various aerobic and anaerobic waste treatment technologies; although municipalities in India invest a lot on creating new Waste Management facilities lack of maintenance and trained manpower becomes Achilles heel in the process. The awareness camps, followed by stringent measures to segregate waste at source and strict actions on disputes related to waste management can bring in the positive change which is essential in present context.

Table 2: Solid Waste Management Status in India [5]

Parameter	Status
House-to-house collection of waste	18 states (of 29)

Segregation of waste at the source	5 states (of 29)
Number of unsanitary landfill sites identified	1,285
Number of sanitary landfill sites constructed	95
Number of ULBs operating compost/ vermicompost facilities	553
Number of ULBs under construction compost/ vermicompost facilities	173
Number of operating pipe composting facilities	7,000
Number of operating RDF facilities	12
Number of operating biogas plants	645
Number of energy generation plants	11 (6 operational)
Waste generation	143,449 Mt/day
Waste collection	117,644 Mt/day (82%)
Waste treated	32,871 Mt/day (28%)

3. Waste to Energy Potential in India

The Municipal Solid Waste is a complex mixture of several wastes which include dry & combustible wastes, wet & biodegradable wastes and other wastes the categories of which have been detailed in Fig.1. The diversity of waste mixture has a hidden energy potential which is not being harnessed by the waste management authorities; leaving apart the government agencies like municipalities even the private industries are not exploring the options to generate electricity from industrial waste. The sector wise energy potential with respect to waste is summarized in Table 2.

Table 3. Summary of sector wise energy potential available for India [6]

Sl. No.	Sectors	Energy potential (in MW)
1	Urban Solid Waste	1247
2	Urban Liquid waste	375
3	Paper (liquid waste)	254
4	Processing and preserving of meat (liquid waste)	182
5	Processing and preserving of meat (solid waste)	13
6	Processing and preserving of fish, crustaceans and molluscs	17
7	Vegetable Processing (solid waste)	3
8	Vegetable Raw(solid waste)	579
9	Fruit Processing (solid waste)	8
10	Fruit Raw (solid waste)	203
11	Palm Oil (solid waste)	2
12	Milk Processing/Dairy Products (liquid waste)	24
13	Maize Starch (liquid waste)	47
14	Tapioca Starch (liquid waste)	36

15	Tapioca Starch (solid waste)	15
16	Sugar (liquid waste)	49
17	Sugar press mud (solid waste)	200
18	Distillery (liquid waste)	781
19	Wine Industry	NA
20	Slaughterhouse (solid waste)	48
21	Slaughterhouse (liquid waste)	263
22	Cattle farm (solid waste)	862
23	Poultry (solid waste)	462
24	Chicory (solid waste)	1
25	Tanneries (liquid waste)	9
26	Tanneries (solid waste)	10
Total (MWeq)		**5690**

The total estimated energy generation potential from **urban and industrial** organic waste in India is approximately 5690 MW.

4. Options for Conversion of Waste to Wealth

With the advent of new technologies the concept is waste disposal in landfills is an outdated one. The waste can be utilized as a resource in several ways; back to square one it is essential to segregate waste at source for making optimal use of the waste. Following sections illustrate the existing technologies in brief.

4.1 Waste to Compost (WtC) Technologies

Composting: Composting is a biological process which involves degradation of organic matter by microbes; since solid waste contains lot of organic matter there is a lot of scope for composting which yields a good soil conditioner; Volume reduction of 50% can be achieved by this method. Composting can be done in three ways.

Aerobic Composting: Composing which is aided by aerobic microbes, in presence of oxygen (air). For large volumes aeration is essential to maintain adequate quantity of air.

Anaerobic composting: This process is accomplished by anaerobic microbes, in the absence of oxygen.

Vermicomposting: An old technology by which earthworms transform the organic matter to compost, requires higher degree of maintenance as compared to aerobic and anaerobic composting.

4.2 Waste to Energy (WtE) Technologies

Biomethanation: Biomethanation or anaerobic digestion occurs in three phases Hydrolysis of organic solids, acetic acid Formation and biogas Production. Biogas is an output of biomethanation of Organic waste by anaerobic bacteria. The process of biomethanation involves breaking complex organic matter in to simpler molecules thereby releasing biogas. The digested material obtained in the form of slurry is organic manure to plants. Biogas is a mixture of methane, carbon dioxide, hydrogen sulphide, water and other compounds in traces [7].

Refuse Derived Fuels: These are the fuels derived from the lighter, dry and combustible materials like paper, card board etc also termed as lighter fractions. The fuel so derived is known as Refuse Derived Fuel {RDF}.These lighter fractions can be used in two ways; they can be shredded and blown in to furnace and mixed with powdered coal or compressed in to pellets/briquettes (known as RDF-Pellets) for economic transportation to steam generation points i.e thermal power plants. RDF pellets can be used in blend with coal to generate steam by making slight modifications in the boiler [8].

Incineration: Incineration involves combustion of solid waste with fuels like petrol or diesel at high temperatures; it aims at reduction of Solid Waste Quantities. Most of the incinerators in India are not serving the purpose of heat recovery. If the heat from incinerator is recovered the incinerator can be an equivalent of thermal power plant. Proper care needs to be taken to avoid air pollution and necessary arrangements have to be made for treatment of plume from the chimneys. Wet waste should not be used in incinerators as lot of energy would be wasted in removing the moisture and the process efficiency will be reduced.

The methodologies for treating the wastes category wise is detailed in Table 4.

Table 4 Appropriate technologies for reuse, recycling, recovery and energy generation from Municipal Solid Waste in India [9]

Sl. No.	Specific Category of Waste	Percentage by Mass (%)	Typical Moisture %	Technology to be adopted	Reduction in waste to be land filled (%)
A	Food waste	6 -26	14	*Composting, Biomethanation*	6 to 31
B	Garden Trimmings	0-20	12		
C	Miscellaneous Organic Substances	0-5	2		
D	Paper	15-45	34	*Recycling, Recovery, RDFs, Incineration*	15 to 49
E	Cardboard	3-15	7		
F	Plastics	2-8	5		
G	Textiles	0-4	2		
H	Wood	1-4	2		
I	Glass	4-16	8	*Reuse, Recycling, Recovery*	4 to 17
J	Rubber	0-1	0.5		
K	Leather	0-2	0.5		
L	Tin Cans	2-8	6		
M	Non Ferrous Metals	0-1	1		
N	Ferrous Metals	1-4	2		
O	Dirt/ Dust & Bricks	0-10	4		

4.3 Technical Analysis

The following technical analysis is intended to provide an insight on the ill effects which can result from disposal of Solid Waste in large quantities through dumping in sanitary landfills.

In India, the waste to an extent of 1,17,644 Metric tonnes of Solid waste is being left untreated [5]. The nominal density of Solid Waste ranges from 450 to 500g/m^3 [10]; the non compact waste requires a mammoth volume of

$$V = \frac{117644 \times 10^3}{0.50} = 0.235\ km^3$$, a cubic space of dimension 0.617 km x 0.617 km x0.617 km

This much of whopping space is required as landfill space per day for non compact waste.

Even if the waste is compacted by 4 times, the volume required to dump the waste will be $0.059\ km^3$ with cubic space of dimension 0.389m x 0.389m x 0.389m per day, which is greater than the lanes of several highways. While the composition of MSW varies geographically and seasonally, the energy density is low—approximately 10-13 MMBTU/ton [6, 7]—well below sub-bituminous coal at roughly 17-21 MMBTU/ton [7-11]. This analysis reveals the fact that enormous space is required to dump the Solid Waste in landfills, if proper techniques are not adopted to minimize and treat the waste the landfills gradually occupy lot of habitable space in India. Apart from swallowing the space, the landfills contaminate ground water, pollute air and affect the nearby ecosystem to a great extent. All these factors call for minimizing the quantity of waste to be disposed and environmental impact assessment needs to be done prior to selection of site for landfill. A properly designed and engineered landfill can reduce the overall impact of waste on environment. The leachate and landfill gas can be harvested from landfills to recover manure and fuel

5. Results and Discussions

The present study has yielded simple methodologies which are prevalent in some of the developed nations. The Solid Waste cannot be considered as a menace any more, it is a resource which needs to be harnessed for the betterment of the nation. Following is the extract of observations derived from the study:

(i) Waste Segregation at source, recycling and recovery of waste can reduce the cost of Waste management to a great extent and provides the space and time for treating the wastes according to their category by doing so, the quantity of waste to be land filled can be reduced by at least 90% and this can reduce the burden on landfills which saves the land area from being accumulated for dumping Solid Waste.

(ii) In current scenario the space of 0.058km^3 (0.389m x 0.389m x 0.389m) to 0.235km^3 (0.617m x 0.617m x0.617m) is required to dispose 1,17,644 metric tonnes of solid waste in landfills.

(iii) Waste to Energy is a promising technology for Solid Waste Management in India with a potential of 5690 MW.

(iv) Waste to Compost is an age old economical approach to transform waste to a useful soil conditioner which can used for organic farming.

(v) The waste needs to be treated as a resource at all stages of waste management from point of generation to site of disposal.

(vi) The land fill gas and leachate can be recovered from sanitary landfills to increase the efficiency of Solid Waste Management System.

6. Conclusion

Following conclusions can be drawn from the investigations carried out:

(i) The legislations in India have to make provisions for suiting the citizens failing to comply with fundamentals like waste segregation, reuse of materials as long as the materials are usable; the citizens role is as important as the government's role in facing the problem of waste management. Incentives have to be provided to the people contributing in waste management.

(ii) Decentralized systems work better in treating the solid waste as centralization renders the systems difficult to operate and maintain. The technologies are available to create wealth out of waste. The waste remains waste unless proper care is taken to harness the hidden potential therein.

(iii) Gradual and sustained efforts are essential to create awareness on importance of Solid Waste Management to general public in urban areas.

(iv) Public Private Partnership (PPP) models have to be incorporated at larger scales to bring more investments on Waste to Energy (WtE) plants.

(v) The Solid Waste Management is one of the fastest growing sectors with numerous entrepreneurial opportunities and is likely to create employment opportunities there by can contribute to the GDP of India.

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Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

7. References

[1] Ministry of Environment, Forest and Climate Change (MOEF&CC) , Government of India

[2] Manual on Municipal Solid Waste Management -2000, Central Public Health and Environmental Engineering Organisation (CPHEEO) Ministry of Housing and Urban Affairs, Government of India

[3] 'Improving Solid Waste Management in India', Zhu., D. et.al., (2008). Available at: http://www.tn.gov.in/cma/swm_in_india.pdf

[4] Kumar Sunil, Smith Stephen R, Fowler Geoff, Velis Costas, Kumar S. Jyoti, Arya Shashi, Rena, Kumar Rakesh and Cheeseman Christopher 2017, "Challenges and opportunities associated with waste management in India" *R. Soc. open sci.* 4160764160764

[5] Solid Waste Management status in India by Central Pollution Control Board, 2016

[6] Ministry of New and Renewable Energy, Government of India

[7] Shamsundar Subbarao and Dhananjaya K N, 2015, Green economy via Decentralised Energy generation and Waste Management being achieved by a 60kg/day Kitchen Waste Biogas Plant at Postal Training Centre, Mysore, India, Proceedings of Micro Energy Systems Conference, 2015

[8] Guidelines on Usage of Refuse Derived Fuel in Various Industries, CPHEEO, Ministry of Housing and Urban Affairs, Government of India, October 2018 (available on http://cpheeo.gov.in/upload/5bda791e5afb3SBMRDFBook.pdf)

[9] Management of Municipal Solid Waste by Ramachandra T V 2006 (https://www.researchgate.net/publication/256477207_Management_of_Municipal_Solid_Waste)

[10] Manual on Municipal Solid Waste Management -2016, CPHEEO, Ministry of Housing and Urban Affairs, Government of India

[11] EIA. 2007. Methodology for Allocating Municipal Solid Waste to Biogenic and Non-Biogenic Energy. Washington, DC: EIA.

[12] EIA. 2018. “Form EIA-923 detailed data with previous form data (EIA-906/920)” https://www.eia.gov/electricity/data/eia923, Accessed June 11, 2021.

[13] EPA. n.d. "Energy Recovery from the Combustion of Municipal Solid Waste (MSW)." https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw. Accessed December 2017.

[14] BETO. 2017. Biofuels and Bioproducts from Wet and Gaseous Waste Streams: Challenges and Opportunities. Washington, DC: BETO.

[15] Seiple, T.E., A.M. Coleman, and R.L. Skaggs. 2017. "Municipal wastewater sludge as a sustainable bioresource in the United States." Journal of Environmental Management 197: 673–680.

[16] Chen, P., X. Qinglong, M. Addy, W. Zhou, Y. Liu, Y. Wang, Y. Cheng, K. Li, and R. Ruan. 2016. "Utilization of municipal solid and liquid wastes for bioenergy and bioproducts production." Bioresource Technology 215: 163–172.