Municipal Solid Waste Management in India-A Compendium Report

SUPREME AUDIT INSTITUTION OF INDIA
लोकहितार्थ सत्यनिष्ठा
Dedicated to Truth in Public Interest

International Centre for Environment Audit and Sustainable Development (iCED), Jaipur, India

In Collaboration with

The Energy and Resources Institute (TERI), New Delhi

2022

About the compendium

This compendium is a part of our endeavour to improve accountability and inculcate professional excellence in the areas of environment and sustainable development. In order to understand and promote effective implementation of Municipal Solid Waste Management (MSWM) in India, International Centre for Environment Audit and Sustainable Development (iCED), Jaipur has compiled this compendium report focused on "Municipal Solid Waste Management in India" in collaboration with the Energy and Resources Institute (TERI), New Delhi. It is hoped that this compendium would be a helpful tool for improving delivery of MSWM services in India.

Feedback

We strive for constant improvement and encourage our readers to provide their valuable feedback / suggestions. Please send us suggestions, comments, and any other feedback about this Paper to iced@cag.gov.in.

Disclaimer

This report is a joint publication of iCED and TERI and have editorial control over the content including opinions, statements and recommendations etc. However, iCED and TERI will not be liable for any loss or damage caused by the reader's reliance on information obtained through this report. The contents of this paper are meant for information and training purpose only and should not be considered as being at par with audit reports or regulations or manuals or other instructions issued from time to time.

Facts and opinions in this Paper are for reference only and they do not in any way represent the official position of O/o the Comptroller & Auditor General of India/Indian Audit & Accounts Department. iCED and TERI disclaim all liability for actions taken or failed to be taken based on any content of this paper.

Message

The Municipal Solid Waste (MSW) management sector is evolving rapidly with new principles of sustainability and technological advancements. The Government of India's flagship scheme Swachh Bharat Mission launched on October 2, 2014 has brought Municipal Solid Waste Management to the forefront of governance. It is an accepted fact that the increasing pace of urbanization in India, along with economic growth and improved living standards have added pressure to already strained capacities of Urban Local Bodies to manage the increasing quantities of municipal waste generated daily. One of the major fallouts of this growth has been the challenge of scientific management of the Municipal Solid Waste generated in Indian cities.

Many Indian cities have shown remarkable progress in waste management by implementing robust models of service delivery coupled with innovative initiatives. To achieve the cleanliness targets in a time-bound manner and with utmost efficiency, all stakeholders must have general awareness of the physical characteristics of waste, basic principles of waste management, modern waste management technologies and best practices of the waste management sector. In this backdrop, International Centre for Environment Audit and Sustainable Development (iCED) in association with the Energy and Resources Institute (TERI) undertook the task to prepare a compendium on Municipal Solid Waste (MSW) management in India.

This publication is a part of iCED's overall innovation-based approach to pedagogic methodologies, including a case study based trainee centric worldview. This publication has been developed comprising various aspects of MSW starting from overview, collection, transportation, processing, treatment and finally to disposal. Further, the significant shortfalls noticed during the audit of waste management by Comptroller and Auditor General of India and results of studies undertaken by interns of iCED on various waste management issues are also included to make this document useful for all the stakeholders. As a joint and concerted effort with TERI, New Delhi, this is also an illustrious beginning which I am optimistic will go further ahead in the years to come.

I sincerely hope that this publication would act as a vital knowledge resource for all stakeholders working in this sector.

I would like to acknowledge the praiseworthy efforts of Dr. Suneel Pandey, Director, Environment and Waste Management Division, TERI, New Delhi and his team from TERI for extending all possible assistance/contributions and feedback at all levels for enriching the contents. I wish to commend the efforts done by my colleague and Director (Training and Research) Shri Pushkar Kumar and the entire team from iCED in making this paper a reality.

01 December, 2022
Jaipur

(Sayantani Jafa)
Additional Deputy C&AG & Director General,
iCED, Jaipur

Foreword

Solid wastes generated as a result of human activities is cause of concern mostly in urban areas of India and the problem is going to be worsened with growing urbanisation and economic development as we aspire to be developed economy in the coming decades. The millions of tonnes of solid waste whether it is Municipal Solid Waste, Industrial Hazardous Waste, Plastic Waste, E-waste, Biomedical Waste or Construction and Demolition Waste are presently problem due to lack of infrastructure for their collection, processing and disposal. This problem can be transformed into opportunity by proper segregation of waste, and maximizing resource recovery and recycling as amply demonstrated by many cities, industries and other stakeholders concerned with the management of waste in the country.

This report is an effort from iCED to provide in a non-technical manner the issues related to various solid waste streams as stated above and the regulatory, policy and institutional framework developed over the years to deal with these waste streams in an effective manner. The key to develop policy framework in the emphasis on the need to reduce waste and maximize resource recovery and recycling so not only address pollution by waste mismanagement but also addressing climate change issues due to uncontrolled emission of GHGs from poorly managed waste. The report also provides technology options available to us to deal effectively with these wastes and strategy and set of recommendation to use these options effectively.

I am sure the readers will have better understanding on the issues related to waste management and ways to achieve effective waste management in the country and congratulate iCED team to come out with this timely publication on the subject.

01 December, 2022

(Suneel Pandey)
Director, Environment and Management Division,
TERI, New Delhi

Acknowledgement

Municipal Solid Waste Management (MSWM) in urban areas has emerged as one of the critical challenges affecting the country. Over the past few years, India's waste management sector has received tremendous attention. The "Swachh Bharat Mission" touches the life of every citizen in some way or the other way and has been one of the largest cleanliness drives.

India has been exponentially increasing the waste processing capacity and many cities have implemented ground-breaking, workable, and resource-efficient models of solid waste management. The second phase of Swachh Bharat Mission will further mainstream the aspects of circular economy in waste management sector. We are moving beyond the targets of open defecation free (ODF) and embarking on the journey of making cities garbage-free, 100 per cent source segregation, door-to-door collection and complete waste processing.

To achieve these objectives, all stakeholders must be equipped with adequate knowledge and resources to plan more efficient waste management systems. Urban Local Bodies (ULBs) across the country should have access to knowledge resources that present strategies for different components of the waste management service chain and aid in scientific waste management.

International Centre for Environment Audit and Sustainable Development (iCED) set-up under the aegis of the Comptroller and Auditor General of India (C&AG) at Jaipur aims to be a global centre of excellence for improving accountability and governance in the area of environment and sustainable development through environment audits by developing high quality products in research enabled by valuable partnership.

With this intent, the publication "Municipal Solid Waste Management in India- A Compendium Report" by iCED in association with TERI is a noteworthy step. It is a compilation of the framework for MSWM in India, waste management strategies including the latest technologies and good practices from the Indian cities to deal with MSW at a single place. Crucial areas of concern gathered from the past audit reports of the Comptroller and Auditor General of India covering this sector are underlined. A dedicated section on research contributions from TERI and iCED (Chapter-5) containing results of various studies undertaken by the interns at iCED along with a list of proposed strategies and

recommendations (Chapter-6) are also included in this compendium to make it broad based and relevant.

I am sincerely grateful to Ms. Sayantani Jafa, Additional Deputy Comptroller and Auditor General of India & the Director General, iCED for leading us with her visionary insights and constant encouragement to take the efforts ahead. I express my gratitude to Dr Suneel Pandey, Director, Environment and Waste Management Division, TERI, New Delhi for providing valuable insights and technical inputs about the sector. I would also like to acknowledge the contributions of all those who directly or indirectly contributed in making this joint publication a reality and appreciate their efforts.

01 December, 2022
Jaipur

Puskar Kumar,
Director (T&R), iCED

Table of Contents

Message I

Foreword III

Acknowledgement IV

Glossary VIII

Summary 1

Introduction 2

Chapter 1. Definition, characteristics and types of Waste 4

1.1 Definitions of Waste 4

1.2 Physical Characteristics of Waste 4

1.3 Classification and sources of waste 6

Chapter 2. Framework and Strategy for Solid Waste Management 9

2.1 Legislative Framework 9

2.1.1 Environment (Protection) Act, 1986 9

2.1.2 Waste Management Rules/Policies 9

2.2 Institutional Framework 11

2.3 Strategies for Waste Management 16

2.4 Waste Processing and Treatment 20

2.5 Selection Criteria for Waste Processing Technologies 23

Chapter 3. Audit of Municipal Solid Waste Management by C&AG of India 26

3.1 Planning 28

3.2 Implementation and Monitoring 28

3.3 Mismanagement 29

3.4 Audit Recommendations and Summing up 30

Chapter -4 Good practices followed by Indian Cities to deal with Municipal Solid Waste 31

4.1 Decentralized waste management in Allepey (Allapuzha) in State of Kerala 31

4.2 Scientific Solid Waste Management in Bobbili in the State of Andhra Pradesh 32

4.3 4R Principle for disposal of waste in Pune City – Decentralized Biogas Plants.....34

4.4 Circular Economy Concept in Indore.....35

4.5 Municipal Solid Waste management in Surat 37

Chapter - 5 Research Contributions from the Energy and Resources Institute (TERI) and International Centre for Environment Audit and Sustainable Development (iCED) 39

5.1 Research contributions from TERI.....39

5.2 Research contributions from iCED 42

Chapter - 6 Recommendations and Proposed Strategies 46

6.1 Municipal Solid Waste 46

6.2 Plastic Waste 47

6.3 Industrial Hazardous Waste.....48

6.4 Biomedical Waste.....48

6.5 E-waste 48

6.6 Construction and Demolition Waste 49

Bibliography 50

Glossary

AQI	–	Air Quality Index
BBMP	–	Bruhat Bengaluru Mahanagara Palike
BMW	–	Biomedical Waste
C&D	–	Construction and Demolition
CPCB	–	Central Pollution Control Board
CPHEEO		Central Public Health & Environmental Engineering Organisation
DfE	–	Design for Environment
DfR	–	Design for Recycling
DOP	–	Directorate of Panchayats
DPR	–	Detailed Project Report
EIA	–	Environmental Impact Assessment
EPR	–	Extended Producer Responsibility
GP	–	Gram Panchayat
GSPCB	–	Goa State Pollution Control Board
GWMC	–	Greater Warangal Municipal Corporation
IEC	–	Information Education and Communication
KSPCB	–	Karnataka State Pollution Control Board
LOTUShr	–	Local Treatment of Urban Sewage Streams for Healthy Reuse
MoEFCC	–	Ministry of Environment, Forest & Climate Change
MoHUA	–	Ministry of Housing and Urban Affairs.
MSW	–	Municipal Solid Waste
MSWM	–	Municipal Solid Waste Management
MTPD	–	Metric Tonnes Per Day
NAMA	–	Nationally appropriate mitigation actions
NNJ	–	Nagar Nigam Jaipur
PRD	–	Panchayat Raj Department
PWM	–	Plastic Waste Management
RDD	–	Rural Development Department
RSPCB	–	Rajasthan State Pollution Control Board
SBM	–	Swachh Bharat Mission
SBM(R)	–	Swachh Bharat Mission Rural
SBM(U)	–	Swachh Bharat Mission Urban
SHG	–	Self Help Groups
SPCB	–	State Pollution Control Board
SWM	–	Solid Waste Management
TPD	–	Tonnes Per Day
UDD	–	Urban Development Department
ULB	–	Urban Local Bodies
UNEP	–	United Nations Environment Programme
VP	–	Village Panchayat
WtE	–	Waste to Energy

Summary

Waste is unwanted and useless material that results from day-to-day activities. With increasing population and changing consumption pattern amid growing urbanization, waste is also increasing rapidly. Global annual waste generation is expected to jump to 3.4 billion tonnes over the next 30 years, up from 2.01 billion tonnes in 2016[1] positing its management as a major governance challenge.

Management of waste or 'waste management' may be defined as the process dealing with the generation, storage, collection, transportation, segregation and disposal of waste. It can be done by discarding, destroying, processing, recycling, reusing or controlling wastes. The prime objective of waste management is to reduce the amount of unusable materials and to avert potential health and environmental hazards. It also involves understanding the grim situation of solid waste in India, mechanisms for waste management, and disposal of solid.

India has been experiencing increasing solid waste management problems. Mismanagement of waste can cause water contamination, soil erosion and air soil erosion and air pollution and eventual adverse health effects and climate change impacts. Moreover, when this waste is not recycled, it usually ends up in landfills or oceans through water bodies posing threat to human health and marine life. Various factors contribute, ranging from weak institutional support to problems with governance affecting waste sector. Existing systems for collection, transportation and disposal of solid waste are mired in chaos and difficulties encountered urban local bodies to manage the problem effectively.

Efficient and effective waste administration is of grave importance to urbanised settlements. It is possible only with the subjective spread of civic sense, understanding and recognising the idea of waste generation. Waste management sector in India has received tremendous attention due to the widespread awareness generated under the flagship program Swachh Bharat Mission (SBM) started in the year 2014. The Compendium on waste scrutinizes the situation of Solid Waste Management (SWM) in India and also offers certain recommendations to address the challenges with special reference to Municipal Solid Waste (MSW).

[1] What a Waste 2.0- Trends in Solid Waste Management

Introduction

This compendium covers various issues and approach for Municipal Solid Waste Management (MSWM) including the regulatory framework, issues in implementation, various waste management technologies and good practices followed by Indian cities to deal with Municipal Solid Waste (MSW).

Solid waste comprises all waste from human as well as animal activities which are solid, useless or discarded as unwanted. SWM is a major environmental challenge all over the world and India is no exception to it. It is an organised process of storage, transportation, processing and safe disposal of solid residuals. A suitable SWM process is based on the source and quality of waste produced. It is generated from several sources, including households, industries, commercial areas and institutions (schools, hospitals, etc.). Disposal of municipal solid waste in an unorganised and improper manner leaves a negative impact on the living conditions of human beings as well as the environment. It generates environmental pollution, generation of toxic gases and leachates due to microbial decomposition, adverse climatic conditions and pollution by landfilling operations. It is one of the causes to spread of communicable/non-communicable diseases among human beings and animals that affect livelihood and economic productivity. The problem of SWM is exacerbated in urban as well as semi-urban areas.

As per annual report of CPCB[2] for the year 2020-21, a total quantity of 160038.9 Tonnes per day (TPD) Solid waste generated in the India and out of which 152749.5 TPD of waste is collected at a collection efficiency of 95.4 percent. Further as per said report, a total of 79956.3 TPD (50 percent) of waste is treated and 29427.2 (18.4 percent) TPD is landfilled. A total of 50655.4 TPD which is 31.7 percent of the total waste generated remains un-accounted. In last five year, the solid waste processing has been increased from 19 percent in 2015-16 to 49.96 percent in 2020-21. The waste disposal of solid waste in form of waste landfilling has been decreased from 54 percent in 2015-16 to 18.4 percent in 2020-21. However, the Solid Waste Generation per capita (gm/day) is observed to be consistent during the year 2015-16 to 2020-21.

The main responsibility to provide SWM services is on the local governing bodies i.e. panchayats and municipalities. Insufficient funds, inefficient technologies and lack of awareness in society are the major causes of poor management of solid waste. The problem is getting compounded by the rise in population and waste generation.

[2] https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf

It has become important to prioritize waste reduction. The system of door-to-door collection may be adopted for the segregation of waste. This is the best possible option to retain the waste in the best possible form which is helpful in optimum composting and recycling.

The most commonly used methods for waste management are dumping on land, dumping in water, reduction and incineration. However, these methods are not applicable to all types of waste. The functional elements of the SWM system are as:

- Waste generation
- Waste handling & separation at source
- Collection
- Separation, processing and transformation
- Transfer and transport
- Disposal (by discarding, destroying, processing, recycling, reusing, or controlling wastes)

Various legislations have been passed for regulating waste disposal. Policies and programmes have been framed by the Ministry of Environment, Forest and Climate Change (MoEFCC) and the Ministry of Housing and Urban Affairs (MoHUA) to improve the current scenario of municipal solid waste management in India. The 12th Schedule of the 74th Constitution[3] Amendment Act of 1992 states that urban local bodies (ULBs) are responsible for keeping towns and cities clean. Judiciaries have also given important decisions from time to time to implement the Acts passed by the Parliament.

Many ULBs lack the necessary infrastructure and face strategic weaknesses. Though ULBs, on behalf of SWM services, collect taxes/charges from people and receive government assistance also, still they continue to be financially fragile. Most of these have failed to achieve their objectives due to one or more reasons viz. the insufficient fund, lack of awareness among the stakeholders and poor implementation of the policies etc.

Given the increasing menace, persisting issues and growing priorities accorded by various stakeholders, a more systematic and pro-active approach for implementation of Solid Waste Management strategies became expedient in a country like India.

[3] https://mohua.gov.in/upload/uploadfiles/files/74th_CAA13.pdf

Chapter 1. Definition, characteristics and types of Waste

1.1 Definitions of Waste[4]

Waste (or wastes) is unwanted or unusable material. Waste is any substance which is discarded after primary use, or is worthless, defective and of no use. A by-product by contrast is a joint product of relatively minor economic value. A waste product may become a by-product, joint product or resource through an invention that raises a waste product's value above zero.

What constitutes waste depends on the eye of the beholder; one person's waste can be a resource for another person. Though waste is a physical object, its generation is a physical and psychological process.

The United Nations Statistics Division Glossary of Environment Statistics describes waste as "materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her purposes of production, transformation or consumption, and of which he/she wants to dispose of. Wastes may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled or reused at the place of generation are excluded."

1.2 Physical Characteristics of Waste

As per Solid Waste Manual 2016[5], 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, radioactive generated in the area under the local authorities and other entities mentioned in rule 2 of the Manual.

Important components[6]:

a) Density: The density of solid waste, or its mass per unit volume (kg/m3), is an important consideration in the design of a SWM system, including the design of sanitary landfills, storage, collection and transport vehicle types, and so on. It often refers to uncompact garbage. To put it another way, the proper operation of a landfill necessitates the compaction of waste to the optimal density. Any standard compaction equipment may reduce waste volume by 75 per cent, increasing an initial density of 100 kg/m3 to 400 kg/m3. In other words, a garbage collection

[4] https://en.wikipedia.org/wiki/Waste#:~:text=Waste per cent20is per cent20any per cent20substance per cent20which,waste per cent20product's per cent20value per cent20above per cent20zero.
[5] https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf
[6] https://www.aboutcivil.org/physical-characteristics-of-solid-waste

vehicle can transport four times the weight of rubbish when it is compacted as opposed to un-compacted waste.

Significant density variations occur spontaneously while garbage moves from source to disposal owing to scavenging, handling, weather wetness and drying, vibration in the collecting vehicle, and decomposition.

It is to be noted that -

i) Increasing the waste's moisture content has a negative impact since increased moisture levels cause the dry density to drop;

ii) The density has an upper limit, and the conservative estimate of in-place density for waste in a sanitary landfill is 600 to 1200 kg/m3.

b) Moisture Content of Solid Waste[7]: Moisture content is defined as the ratio of the weight of water (wet weight - dry weight) to the total weight of the wet waste. It is one of the important physical characteristics of solid waste. It increases the weight of solid waste thereby increasing the cost of collection and transport. Furthermore, because wet waste requires energy for the evaporation of water and raising the temperature of water vapour, the moisture content is an important factor in the economic feasibility of waste treatment by incineration. In general, waste should be protected from rain and other outside water.

The usual moisture content range is 20 to 40 per cent, which reflects the extremes of waste in an arid climate and during the rainy season in an area with considerable precipitation. Values above 40 per cent, however, are not unusual. Apart from climatic factors, low-income nations often have higher moisture content due to the greater percentage of food and yard waste.

c) Size of Waste Constituents[8]: Due to its relevance in the design of mechanical separators, shredders, and waste treatment processes, the size distribution of waste elements in the waste stream is crucial. This varies greatly, hence it is important to properly analyse the waste characteristics while developing a system.

d) Calorific Value[9]: Calorific value is the amount of heat generated from the combustion of a unit weight of a substance, expressed as kcal/kg. The calorific value is determined experimentally using a Bomb calorimeter in which the heat generated at a constant temperature of 25°C from the combustion of a dry sample is measured.

[7] http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2595
[8] http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2595
[9] http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2595

Industrial waste, hazardous waste, hazardous chemicals, biomedical wastes, e-waste, lead acid batteries and radio-active waste, are covered under separate rules framed under the Environment (Protection) Act, 1986[10].

1.3 Classification and sources of waste[11]

- Municipal Solid waste
- Domestic Waste
- Commercial Waste
- Industrial solid waste including Hazardous waste
- Agricultural Waste
- Biomedical Waste
- Plastic Waste
- E-waste
- Construction and Demolition waste

1.3.1 Municipal Solid waste[12]

Municipal solid waste includes commercial and domestic wastes generated in municipal or notified areas or either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes.

1.3.2 Domestic waste[13]

Domestic waste is one of the most important components of MSW. Domestic wastes include food waste, paper, glass, metals, plastics, textiles, etc. A large part of domestic waste consists of plant and animal waste such as vegetables, fruit peel, bone and meat waste etc. which are considered wet wastes. Paper, cardboard, old newspapers, books, plastic items, disposable dishes, toys, metal, glass cans obsolete items etc. also make up another large portion of domestic dry waste.

1.3.3 Commercial waste[14]

Commercial waste consists of waste from premises used mainly for the general purposes of a business or trade or recreation, education, sport, or entertainment. It does not include household, agricultural, or industrial waste as a result of construction activities. It doesn't matter whether the waste is generated in a residential or a commercial area. For example, the waste generated by a lawn-mowing company on the premises of the client's home is commercial waste. Commercial waste is non-hazardous.

[10] https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf
[11] https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
[12] https://vikaspedia.in/energy/environment/waste-management/municipal-solid-waste-management
[13] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/domestic-waste
[14] https://envirocareusa.com/blog/356-differences-between-commercial-and-domestic-waste

1.3.4 Industrial wastes[15] including Hazardous waste[16]

The term industrial waste describes toxic waste from industrial operations including mining, refining the metallic and non-metallic resources and using these resources in the manufacturing processes to produce different intermediates of products. Sectors like food processing industries, metallurgical, crude petroleum refining, chemical and pharmaceutical operations, fertilizer, cement, and breweries among other sectors produce industrial waste. The most affected is the health of people residing nearby the dumping sites. Industrial waste causes harm to the water bodies causing the destruction of fish, pollution of groundwater and release of foul odors.

Hazardous waste: Any waste that poses a threat to human health and the environment if not handled or managed properly. For this reason, many countries have strict regulations on the storage, collection and treatment of hazardous waste. The Basel Convention and the OECD Decision include lists of waste streams, characteristics and components that fall within the definition of hazardous waste. Most hazardous waste originates from industrial production.

1.3.5 Agricultural Waste[17]

The waste generated by agriculture includes waste from crops and livestock.

Some of the waste is produced by agro-based industries viz. rice milling, tobacco etc. Agricultural wastes include rice husk, stubble/parali, degasses, ground nut shells and straws of cereals etc.

1.3.6 Biomedical waste[18]

It is a form of infectious waste and involves waste from the treatment of diseases in humans and animals. This type of waste usually consists of medicines, sharp objects, bandages, chemicals, pharmaceuticals, body fluids and body parts (from amputations and surgery). Healthcare waste may be infectious, toxic or radioactive.

1.3.7 Plastic Waste[19]

Plastic is the general common term for a wide range of synthetic or semi-synthetic organic amorphous solid materials derived from oil and natural gas. The word 'Plastic' is derived from the Greek word '**Plastikos**' meaning fit for moulding & '**Plastos**' meaning moulded.

[15] https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
[16] https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
[17] https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
[18] https://www.environmental-auditing.org/media/5375/wgea-waste-managemen_e.pdf
[19] http://jkspcb.nic.in/Content/Plastic.aspx?id=230

1.3.8 E-Waste[20]

E-waste is a generic term for waste originating from out of life electric and electronic equipment, such as computers, televisions mobile phones and home appliances etc. Some component of E-waste is categorised as hazardous waste due to their toxic components, such as lead, quicksilver, cadmium, mercury and brominated flame retardants. These materials can cause health damage if not treated properly.

1.3.9 Construction and Demolition waste

Construction and demolition (C&D) waste is generated from construction, renovation, repair, and demolition of houses, large building structures, roads, bridges, piers, and dams. C&D waste is made up of wood, steel, concrete, gypsum, masonry, plaster, metal, and asphalt. C&D waste is notable because it can contain hazardous materials such as asbestos and lead. Estimates vary, but a commonly accepted estimate is that between 15 per cent and 20 per cent of municipal solid waste comes from construction and demolition projects.

[20] https://www.environmental-auditing.org/media/5375/wgea-waste-managemen_e.pdf

Chapter 2. Framework and Strategy for Solid Waste Management

2.1 Legislative Framework

Article 51-A (g) (fundamental duties) of the Constitution of India, states that "It shall be the duty of every citizen of India to protect and improve the natural environment including forests, lakes, rivers and wildlife and to have compassion for living creatures." Article 48A of the Constitution directed the State to protect and improve the environment and to safeguard forests and wildlife. Waste along with climate change, pollution and loss of biodiversity is one of the critical environmental challenges facing India. The judicial interventions[21] also played a significant role in creation of rules and regulations and effective implementation of waste management in India. The various legislative measures are discussed below:

2.1.1 Environment (Protection) Act, 1986

The Act seeks to protect and improve the environment and matters connected therewith. It empowers the Central Government to establish authorities [under section 3(3)] charged with the mandate of preventing environmental pollution in all its forms and tackling specific environmental problems. It is an umbrella act. There are various central institutions working together for effective waste management in India and main objectives of these institutions are to ensure effective waste management.

2.1.2 Waste Management Rules/Policies

The Central Government has the power to take measures necessary for protecting and improving the quality of the environment, subject to the provisions of the Environment (Protection) Act, 1986 and notified waste management rules from time to time as per details given in the following paragraphs:

2.1.2.1 National Environment Policy, 2006[22]

National Environment Policy 2006 is a response to India's national commitment to a clean environment, mandated in the Constitution in Articles 48 A and 51 A strengthened by multiple judicial interpretations. It is recognized that the maintenance of a healthy environment is not

[21] (a) Municipal Council, Ratlam vs. Shri Vardichand and others (1980) – Supreme Court opined that lack of finances cannot be the reasons for not discharging statutory duties. (b) B.L. Wadhera vs. Union of India (1994) – Supreme Court issued directives to Delhi Municipal Corporation regarding the collection, transportation and disposal of garbage and hospital waste. (c) Ms. Almitra Patel vs. Union of India (1996) - Supreme Court constituted a committee to look into SWM in Class I cities i.e. cities with a population of over one lakh.
[22] Extract from National Environment Policy, 2006

the responsibility of the State alone. It is the responsibility of every Citizen and thus a spirit of partnership is to be realized through the environment Management of the country.

The Policy evolved from the recognition that only such development is sustainable, which respects ecological constraints, and the imperatives of justice. The objectives are to be realized through various strategic interventions by different public authorities at the Central, State, and Local Government levels.

2.1.2.2 Solid Waste Management Rules, 2016[23]

On April 08, 2016, the Union Ministry of Environment, Forests and Climate Change (MoEF&CC) notified the new Solid Waste Management Rules (SWM), 2016 that replaced the Municipal Solid Wastes (Management and Handling) Rules, 2000. The new rules further categorised six waste management rules i.e. Solid Waste Management (SWM), plastic waste, e-waste, biomedical waste, hazardous waste and construction and demolition waste management rules. The salient features of Solid Waste Management Rules, 2016 are:

- The Rules become applicable beyond Municipal areas and further extended to urban agglomerations, census towns, notified industrial townships, areas under the control of Indian Railways, airports, airbases, port and harbour, defence establishments, special economic zones, State and Central government organizations, places of pilgrims, religious & historical importance.
- The source segregation of waste has been mandated to channelize the waste to wealth by recovery, reuse and recycling.
- Responsibilities of generators have been introduced to segregate waste into three streams, wet (Biodegradable), dry (Plastic, Paper, metal, wood, etc.) and domestic hazardous wastes (diapers, napkins, empty containers of cleaning agents, mosquito repellents, etc.) and handover segregated wastes to authorized rag-pickers or waste collectors or local bodies.
- The concept of partnership in Swachh Bharat has been introduced. Bulk and institutional generators, market associations, event organizers and hotels and restaurants have been made directly responsible for segregation and sorting the waste and managing in partnership with local bodies.
- The bio-degradable waste should be processed, treated and disposed of through composting or bio-methanation within the premises as far as possible.

[23] Extract of Solid Waste Management Rules, 2016

- The developers of Special Economic Zone, industrial estate and industrial park to earmark at least five per cent of the total area of the plot or a minimum of five plots/sheds for recovery and recycling facility.
- All manufacturers of disposable products such as tin, glass, plastics packaging etc. or brand owners who introduce such products in the market shall provide necessary financial assistance to local authorities for the establishment of waste management system.
- Manufacturers or Brand Owners or marketing companies of sanitary napkins and diapers should explore the possibility of using all recyclable materials in their products or they shall provide a pouch or wrapper for disposal of each napkin or diapers along with the packet of their sanitary products.
- Horticulture waste and garden waste generated from his premises should be disposed of as per the directions of local authority.

2.2 Institutional Framework

As per the Constitution of India, SWM is a state subject[24] and it is the primary responsibility of state governments to ensure that appropriate solid waste management practices are introduced in all the cities and towns in the state. The 74th amendment of the constitution also entrusted the urban local bodies to execute this responsibility to plan, design, operate, and maintain the solid waste management system in their respective cities/towns. The solid waste management rules identifies a number of ministries agencies/ departments and prescribe their roles and responsibilities.

The role of the Government of India is broadly to formulate policy guidelines and provide technical assistance to the states/cities whenever needed. It also assists the state governments and local bodies in human resource development and acts as an intermediary in mobilizing external assistance for the implementation of solid waste management projects. The Ministry of Environment & Forests, Government of India notified various rules and regulations time to time for management of Municipal Solid Waste, which make it mandatory to adopt appropriate technologies with due authorization by the CPCB. The MSW rules has specific directives to the Local Bodies, District Administrations and the Urban Development Department of State Governments to provide facilities for collection, transportation, treatment & disposal of

[24] http://cpheeo.gov.in/upload/uploadfiles/files/Advisorypercent20onpercent20Improvingpercent20Municipalpercent20Solidpercent20Wastepercent20Managementpercent20Services.pdf

municipal solid waste in a scientific and hygienic manner. The details of some the institutions working at central/state level are as under:

2.2.1 Ministry of Environment, Forest and Climate Change

The Ministry of Environment, Forest and Climate Change (MoEFCC) is the nodal agency for the planning, promotion, co-ordination and overseeing the implementation of India's environmental and forestry policies and programmes. The primary concerns comprise of formulation and implementation of policies and programmes relating to conservation of the country's natural resources, and the prevention and abatement of pollution.

These objectives are well supported by a set of legislative and regulatory measures of waste management issued by ministry from time to time. Some of them are MSW (Management and Handling) Rules -2000, Manual on MSW Management and Handling Rules -2000, National Environment Policy -2006 and Solid Waste Management Rules, 2016 etc. Besides the rules provides for Central Monitoring Committee comprising members from different ministries/ agencies chaired by the Secretary, MoEF&CC.

2.2.2 Ministry of Housing and Urban Affairs

The Ministry of Housing and Urban Affairs (MoHUA) is a ministry of the Government of India with executive authority over the formulation and administration of the rules and regulations and laws relating to the housing and urban development in India. The ministry is entrusted with role of providing technical guidelines and project finances on solid waste management and ensure implementation of these rules. These objectives are well supported by a set of legislative and regulatory measures of waste management. The Ministry of Urban Development has published the Municipal Solid Waste Management Manual, 2016 in alignment with the SWM Rules, 2016. This revised manual is based on 16 years of learning experience gained in India post the publication of its first edition in 2000.

The role of ministry has been significantly increased after the launch of flagship program of Swachh Bharat Mission (SBM), Swachh Bharat Abhiyan or Clean India Mission, a country-

wide campaign initiated by the Government of India in 2nd October, 2014 to eliminate open defecation and improve solid waste management.

Swachh Bharat Mission

The Swachh Bharat Abhiyan (SBA or SBM) was introduced by the Government of India on October 2nd, 2014. The logo for SBM signifies the vision of Mahatma Gandhi and contains the spectacles of Mahatma Gandhi with the bridge of the spectacles in the National Tricolour. It signifies the entire nation uniting to achieve the vision of Mahatma Gandhi for a clean India. The tagline 'Ek Kaddam Swachta Ki Aur', exhorts all citizens to contribute in their own way towards achieving Swachh Bharat. SBA covers all the rural as well as urban areas all over India. The Ministry of Housing and Urban Affairs has been monitoring the urban part of the mission. The erstwhile Ministry of Drinking Water and Sanitation and now revamped as Ministry of Jal Shakti has been entrusted to work on the rural part of the mission.

The key thrust areas of the **Swachh Bharat Mission (Urban)** include:

- Elimination of open defecation
- Eradication of Manual Scavenging by converting insanitary toilets to sanitary
- Modern and Scientific MSWM
- Effecting behavioural change regarding healthy sanitation practices
- Awareness generation about sanitation and its linkage with public health
- Capacity Augmentation for Urban Local Bodies (ULBs) to create an enabling environment for private sector participation.
- Improving the levels of cleanliness through SWM activities in statutory towns.

A total of around fourteen thousand crores were allotted by central government to States/UTs in India under SBM (U) from the year 2014 to 2021.

The broad objectives of the **Swachh Bharat Mission (Rural) are:**

- To bring about an improvement in the general quality of life in the rural areas, by promoting cleanliness, hygiene and eliminating open defecation.
- To accelerate sanitation coverage in rural areas to achieve the vision of Swachh Bharat
- To motivate Communities and Panchayati Raj Institutions to adopt sustainable sanitation practices and facilities through awareness creation and health education.
- To encourage cost effective and appropriate technologies for ecologically safe and sustainable sanitation.
- To develop where required, Community managed sanitation systems focusing on scientific Solid & Liquid Waste Management systems for overall cleanliness in the rural areas and becoming rural India Open Defecation Free.

For spreading awareness on sanitation and disseminating the inspiration journey of Swachh Bharat Mission (Gramin), a permanent Audio Visual Experiential centre, Rashtriya Swachhata Kendra (RSK) has been set up in New Delhi.

2.2.3 Central Pollution Control Board

The Central Pollution Control Board (CPCB) of India is a statutory organization under the Ministry of Environment, Forest and Climate Change (MoEFCC). It was established in

1974 under the Water (Prevention and Control of Pollution) Act, 1974. The CPCB is also entrusted with the powers and functions under the Air (Prevention and Control of Pollution) Act, 1981.

It serves as a field formation and also provides technical services to the Ministry of Environment and Forests under the provisions of the Environment (Protection) Act, 1986. It Co-ordinates the activities of the State Pollution Control Boards (SPCB) by providing technical[25]assistance and guidances on MSW such as Management of sanitary waste and disposal of Legacy Waste (Old Municipal Solid Waste) etc. It also resolves disputes among SPCBs and also collects necessary information form municipal authorities and provide technical assistance. It has pivotal role in standard setting, review, monitoring, reporting and coordination for implementation of MSW under the rules.

The rules also prescribe significant roles for Ministry of Chemicals and Fertilizers, Ministry of Agriculture, Ministry of Power, Ministry of New and Renewable Energy at the central level.

2.2.4 State Urban Development Department

The Secretary-in-charge of the Urban Development Department (UDD) of the concerned state or union territory has the overall responsibility for the implementation of MSWM systems in cities and towns in line with SWM Rules. UDD is required to prepare a state policy and strategy for MSWM in the state. UDD has to report on SLBs for SWM service provision in ULBs to the Ministry of Urban Development (MoUD). UDD is also responsible for approval of land transfer from state to ULBs (for all projects). States have the power to regulate the creation of staff positions (technical and non-technical) in the ULBs. For implementation of the provisions under the rules at district level, role and responsibilities of district magistrates have also be prescribed under the rules.

2.2.5 State Pollution Control Board

Likewise CPCB, the SPCB is the main agency responsible for the administration and enforcement of Acts and Rules pertaining to environment in the state. The SPCBs are responsible for monitoring the implementation of provisions of MSW Rules. The SPCBs are also responsible for monitoring and implementing these rules such as compliance of standards regarding groundwater, ambient air, leachate quality and the compost quality including incineration standards as prescribed. The SPCBs issue authorisation to Municipal authorities or to the operators about the compliance criteria and standards as specified in these rules. The

[25] https://cpcb.nic.in/technical-guuidelines/

municipalities are required to send a copy of annual report to the SPCBs every year and then consolidated report is submitted to CPCB for effective implementation of MSW Rules.

2.2.6 City Municipal Corporations/City Municipal Councils/ Town Municipal Councils

The SWM Rules, 2016 stipulate that every ULB shall prepare a MSWM plan for:

- Institutional strengthening
- Human resources development
- Technical capacity building
- Financial capacity and arrangements (public private partnership [PPP] framework)
- Community participation
- Legal framework and mechanism for enforcement
- Public grievance or complaint redresses.

The role of various authorities at state level and urban local bodies is shown in below mentioned figure:

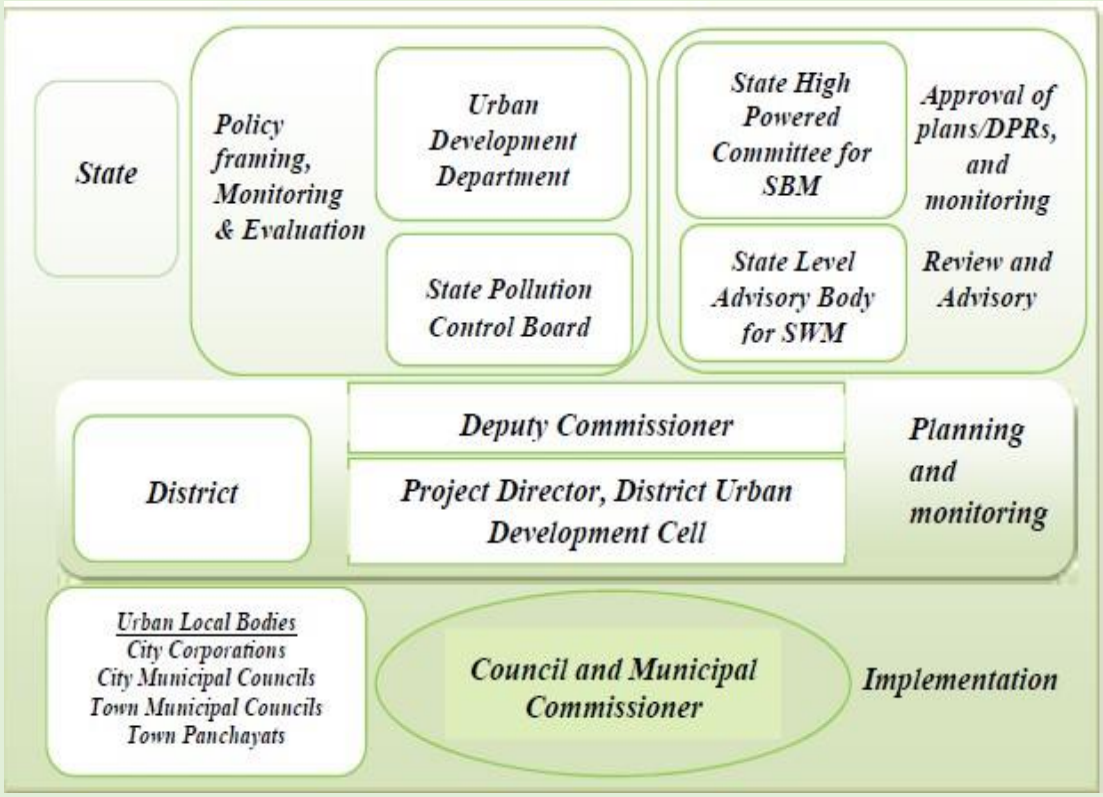

Figure 2.1: Role of various authorities in Urban Solid Waste Management[26]

[26] Report No. 4 of the year 2018 of Government of Karnataka on Performance audit of Solid Waste Management in Urban Local Bodies

2.3 Strategies for Waste Management

Importance of 3-Rs i.e. reduce, reuse and recycle is vital for MSWM. Rules, manual and guidelines for implementation of Waste Management have been published at central and states level. The manual on MSWM brought out by the Ministry of Urban Development in 2016 provides, guidance to urban local bodies on the planning, design, implementation and monitoring of municipal solid waste management systems. The manual clearly provides 'A seven step approach for MSWM Planning' to be adopted by urban local bodies for preparing, revising and implementing Municipal Solid Waste Management Plans (MSWM Plans). The following seven steps provide an overview of the planning process of MSW:

- Policies, Programmes and Legal Framework
- Assessment of Current Situation and Gap Analysis
- Stakeholder Consultation for Planning
- Preparation of Draft Municipal Solid Waste Management Plan
- Schedule for Implementation
- Stakeholder Consultation for Municipal Solid Waste Management Plan Validation
- Municipal Council Approval for Municipal Solid Waste Management Plan and Implementation Including Public Private Partnership

Targets of 3-Rs can be achieved through an integrated strategy for Waste Management covering various stages such as segregation, collection, transportation of waste and their processing and treatment as discussed in succeeding paragraphs:

2.3.1 Waste Minimisation[27]

Source reduction is the most preferred approach given its potential to directly reduce the quantity of waste generated and associated financial and environmental costs. It includes activities that reduce waste generated as a result of product creation and use. It also encompasses those activities that increase product durability, re-usability and reparability.

[27] Municipal Solid Waste Manual-II issued by MoHUA

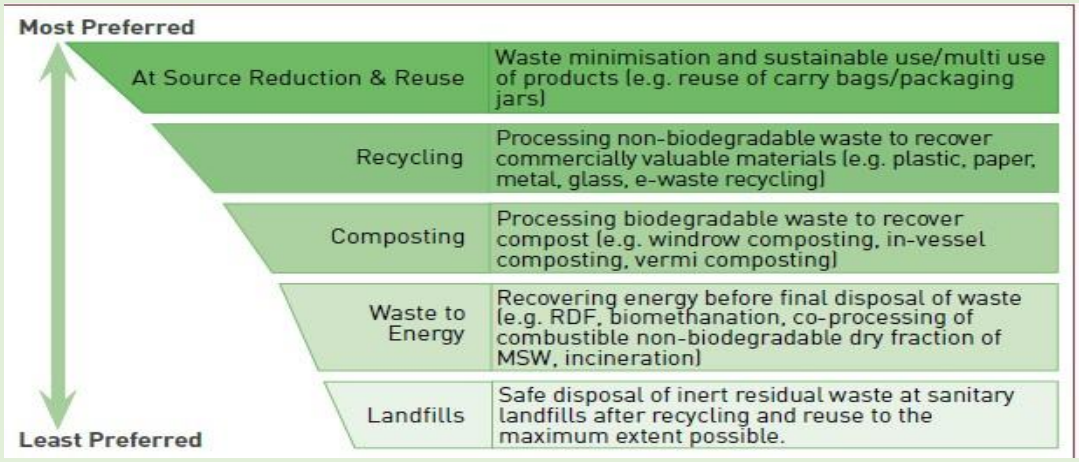

Figure 2.2: Waste Minimisation in the Integrated Solid Waste Management (ISWM) Waste

Some of the important steps towards waste minimization are given below:

- Promotion of voluntary action by encouraging business groups to reduce volumes of packaging, while maintaining the requisite strength.
- Develop eco-labelling standards based on the potential for waste reduction due to product packaging and potential for recycling and reuse.
- Promote development of eco-industrial parks, which are industrial areas where material and resource exchange synergies are established between businesses and industries. Such parks might operate facilities for recycling and product reuse processes.

2.3.2 Source Segregation

Segregating waste at source ensures that waste is less contaminated and can be collected and transported for further processing. It also optimizes waste processing and treatment technologies and results in high proportion of segregated material that could be reused and recycled, leading to less consumption of virgin material.

The local community should be educated and encouraged to perform the following actions to ensure the collection of segregated waste:

- At the household level, MSW should be segregated into wet, dry, and domestic hazardous waste fractions, at a minimum, and stored in separate containers.
- Waste should be placed at the doorstep before the appointed time of collection.
- Domestic hazardous waste such as batteries, tube lights, chemical, paint, and insecticide containers etc. should be handed over separately to the waste collectors or at the domestic hazardous waste deposition centres for safe disposal.

- Sanitary waste (e.g. diapers, sanitary napkins, tampons, incontinence sheets and any other similar waste) should be wrapped securely in the pouches and handed over separately to the waste collectors daily.

BASIC SEGREGATION					
Wet waste (green bin)	Dry waste (Blue bin)				Domestic Hazardous[7]
	With further sub-segregation BASIC+				
Food wastes of all kinds, cooked and uncooked, including eggshells and bones, flower, fruit and waste including juice, vegetable peels and household garden/plant wastes. Soiled tissues, food wrappers, paper towels; fish and meat	Paper cardboard and cartons	Containers & packaging of all kinds excluding those containing hazardous materials Compound packaging (tetrapak, blisters etc.) Plastics	Rags Rubber Wood Discarded clothing Furniture	Metals Glass (all kinds) Inerts House sweepings and inerts (not garden, yard or street sweepings)	E-waste* Hazardous wastes** Household medical waste*** Batteries from flashlights and button cells. Lights bulbs, tube lights and Compact Fluorescent Lamps (CFL) Car batteries, oil filters and car care products and consumables

* E-waste: Printer & printer cartridges, electronic parts and equipment and others

** Hazardous wastes: Chemicals and solvents and their empty containers, paints, oil, lubricants, glues, thinners and their empty containers, insecticides, pesticides and herbicides and their empty containers, photographic chemicals, bleaches and household kitchen & drain cleaning agents

*** Household Medical Waste: Thermometers and other mercury containing products, discarded medicines, injection needles and syringes after destroying them both, sanitary wastes and diapers (should be collected daily)

Figure 2.3: Indicative List for Segregation of Household Wastes[28]

2.3.4 Collection and Transportation[29]

Collection of wet, dry and domestic hazardous waste separately ensures maximum recovery of recyclables. It also enhances the potential for cost-effective treatment of such wastes which can then easily meet the minimum quality criteria defined for different products. Waste collection and transportation services are broadly divided into two categories i.e. primary and secondary:

2.3.4.1 Primary Collection

Primary collection refers to the process of collecting, lifting and removal of segregated solid waste from the source of its generation including households, shops, offices, markets, hotels, institutions and other residential or non-residential premises and taking the waste to a storage

[28] Manual on Municipal Solid Waste Management (First Edition), Central Public Health and Environmental Engineering Organisation (CPHEEO), 2000, Ministry of Urban Development

[29] Municipal Solid Waste Manual-II issued by MoHUA

depot or transfer station or directly to the disposal site. Primary collection must ensure separate collection of certain waste streams or fractions depending on the separation and reuse system applied by the respective town or city. The municipalities should establish a system to recognise organisations of waste pickers or informal waste collectors and to facilitate their participation in solid waste management including door-to-door collection of waste.

2.3.4.2 Secondary Collection

The secondary collection includes picking up waste from community bins, waste storage depots, or transfer stations and transporting it to waste processing sites or to the final disposal site. At the secondary collection points, segregated waste must be stored on-site in separate covered bins or containers for further collection and should be kept separate during all steps of waste collection, transportation, and processing. Further, ULBs should ensure that at the secondary storage points the waste is attended to daily or before container starts overflowing.

2.2.4.3 Primary Transportation

It should be ensured that waste collected from the doorstep in motorized vehicles should be either directly transported to the processing facility or through material recovery facility or transfer station, or waste storage depots for facilitating, sorting, and bulk transfer of waste. The vehicles used for transportation should be covered and not visible to the public. It should have a facility to prevent spillage of waste.

2.2.4.4 Secondary Transportation

The SWM Rules, 2016 define secondary storage as, "the temporary containment of solid waste after collection at secondary storage depots or MRFs or Bins for onward transportation of waste to the processing or disposal facility". The secondary collection includes picking up waste from community bins, waste storage depots, or transfer stations preferably in larger vehicles and transporting it to waste processing sites or to the final disposal site. The ULBs should ensure that unsegregated waste should be segregated either at an intermediate stage or at the processing plant, prior to treatment. Larger capacity vehicles should transport waste in covered manner from the secondary or tertiary collection point (depot or transfer station) to the processing and treatment facility or landfill. The vehicles used for this purpose should be equipped with modern technologies viz. Monitoring Information Systems (VTMS), Geographic Information System (GIS), Global Positioning System (GPS), Radio Frequency Identification (RFID), and General Packet Radio Services (GPRS) etc.

2.4 Waste Processing and Treatment

Processing and treatment of solid waste shall be as per the schedules provided in SWM Rules, 2016. Processing[30] and treatment[31] of solid waste and adoption of processing technologies largely depend upon the quantity and characteristics of the total waste generated. It is essential to quantify and characterise the waste generated by the local body before adopting any processing and treatment technology.

2.4.1 Recycling and Recovery

Local bodies must try to establish the linkages with market for the recyclable products. The products made from the recyclable material must also meet the market requirements. It will enhance the local economy and providing livelihood opportunities to recyclers in the recycling industry. Recycling would signify sustainable use of resources. Less amount of waste goes to storage sites and less usage of land. It will also reduce environmental impacts and impacts of climate change. Informal sector in recycling process must be involved as the informal sector aptly supplements the formal sector.

Most of the waste in India is collected by the unorganized sector. Millions of people, including women are depended on garbage collection for their livelihood. Similarly, kabadiwalas also collect newspapers, empty cans and bottles etc. from houses every day. These waste pickers are not educated but no attention is paid to providing training for them by the local bodies. It is necessary to provide training to them about what is the scientific method of collecting waste, which waste can be averse to health if picked up carelessly, how the waste is segregated, what precautions are necessary to be taken during the picking of garbage etc. Further, they should be brought under organized sectors in engaged in managing waste. ULBs need to setup material the recovery facilities or secondary storage facilities with sufficient space for sorting of recyclable materials to enable informal or authorised waste pickers and waste collectors to separate recyclables from the waste and provide easy access to waste pickers and recyclers for collection of segregated recyclable waste such as paper, plastic, metal, glass, textile from the source of generation or from material recovery facilities; Bins for storage of different types of waste i.e. Bio-degradable wastes, recyclable wastes other wastes should be printed in different colours.

[30]Processing means any scientific process by which segregated solid waste is handled for the purpose of reuse, recycling or transformation into new products. (SWM Rules, 2016)

[31] Treatment means the method, technique or process designed to modify physical, chemical or biological characteristics or composition of any waste so as to reduce its volume and potential to cause harm. (SWM Rules, 2016)

2.4.2 Composting[32]

Composting is a biological process in which microorganisms convert organic matter into compost. MSW primarily consists of organic, inorganic, and inert fractions. Under natural conditions, the organic fraction of waste continually decomposes, accompanied by a strong foul odour and production of gases, which are predominantly methane or CO2 depending on the aerobic[33] condition of the decomposing mass. Composting is a process of controlled decomposition of organic waste, typically in aerobic conditions, resulting in the production of stable humus-like products, i.e., compost. Considering the typical composition of wastes and the climatic conditions, composting is highly relevant in India and should be considered in all municipal solid waste management (MSWM) concepts.

[32] https://mohua.gov.in/upload/uploadfiles/files/Part2.pdf
[33] Aerobic composting uses oxygen and bacteria and replicates natural decomposition. The process of aerobic composting can be used with all types of organic waste.

Composting of Kitchen Waste at iCED

iCED, Jaipur as a global centre of excellence in the area of environment and sustainable development promotes environment friendly practices at its own campus. For disposal of organic waste generated in the campus iCED adopted pit composting. Organic waste is collected from kitchen area of the hostel canteen/tiffin rooms and staff residences at iCED campus. First stage of composting of Organic Waste is segregation into bio-degradable (all vegetable and fruit wastes, grains, coffee grounds, tea bags, fruit or vegetable pulp and egg shells etc.), recyclable (packaging items including milk bags) and non-recyclable (meat waste, skins, fish waste, cheese and such type of dairy products and Grease and oils etc. because they unbalance the otherwise nutrient-rich structure of other food and vegetation waste and breakdown slowly with other issues) by using three types of separate bins. Shredding of organic waste/ food waste into smaller pieces is done with the help of a shredder machine. To prepare compost a big pit is used near the garden area where shredded waste is transport. At present there are six such pits at iCED campus. The organic waste is duly dumped in selected pits. Organic waste received is mixed with dry garden refuse in the ratio of 1:30 and a layer (2 – 3 inch) of soil or sand is added at the bottom of the pit. Later a fine bedding is prepared by adding partially decomposed cow dung, dried leaves and other biodegradable wastes collected from fields and kitchen. It is distributed evenly on the sand layer because when one or more element is not in balance, aerobic decomposition is not optimal. This is when it takes longer or remains incomplete. It's just like getting the right balance of materials while cooking. Activator/Bio-clean compost chemical for speeding up the composting process is added/sprayed wherever felt necessary. The pit is covered with a thatch roof to prevent the entry of ants, lizards, mouse, snakes, etc. and protect the compost from rainwater and direct sunshine. Water is added to the mixture for speeding up the composting process. Frequent checks are done to avoid the compost from overheating. Proper moisture and temperature by turnings and subsequent staking is done. After an interval of few days, a rake is used to give the pile of waste a quick turn. This provides enough aeration for the waste to decompose successfully. The compost is used once it gets ready within a period of 2-3 months in garden areas or potted plants once the dry, dark brown waste-turned-compost is ready.

2.4.3 Waste to energy

Waste to energy refers to the process of generating energy in the form of heat or electricity from solid waste. It can be achieved through:

- Thermal processes like incineration or combustion of refuse-derived fuel (RDF); and

- Biological processes like biogas methanation and further conversion of biogas into electrical power or automotive fuel (compressed biogas). Biogas can also be used for thermal applications (heating or cooking).
- In order to deal with the fastest-growing waste streams, IIT Delhi has developed a zero-emission technology to manage and recycle e-waste for wealth. As per researchers, e-waste is shredded and pyrolyzed to yield liquid and gaseous fuels leaving behind metal-rich solid fractions.

2.4.3.1 Refuse Derived Fuel (RDF)

The SWM Rules, 2016 define refuse-derived fuel (RDF) as "fuel derived from the combustible waste fraction of solid waste like plastic, wood, pulp or organic waste, other than chlorinated materials, in the form of pellets or fluff produced by drying, shredding, dehydrating and compacting of solid waste". It is used as a fuel for either steam or electricity generation or as an alternate fuel in industrial furnaces or boilers (co-processing or co-incineration of waste in cement, lime, and steel industry and for power generation). The duties and responsibilities of local bodies for RDF have been prescribed in the SWM Rules, 2016 and SWM Manual, 2016.

2.4.3.2 Bio-methanation

Bio-methanation is the anaerobic fermentation of biodegradable matter in an enclosed space under controlled conditions. The waste mass undergoes decomposition due to microbial activity, thereby generating biogas comprising mainly methane and carbon dioxide (CO2), and also digested sludge, which is almost stabilised but may contain some pathogens. Bio-methanation like composting is one of the most technically viable options for solid waste in Rajasthan State due to the presence of high organic and moisture content. The duties of waste generators and duties and responsibilities of local bodies for bio-methanation have been prescribed in the SWM Rules, 2016 and SWM Manual, 2016.

There are many other modern technologies available worldwide and details of some of the updated technologies are given in Annexure-B.

2.5 Selection Criteria for Waste Processing Technologies

Selection of appropriate technology is one of the key considerations for the success of a waste management system for a particular town/city. The efficiency of a technology depends upon the criteria for which it is designed and planned. The major criteria considered for the selection of technologies are the waste quantity, waste characteristics, physical properties and composition of wastes, availability of land, social factors, capital investment, duration of treatment, products market, etc.

A table summarizing the important opportunities and challenges of some of the widely used technologies are detailed below:

(**Table 2.1:** Opportunities and challenges of waste processing techniques[34])

Sl. No.	Name of waste Treatment Technology	Opportunities	Challenges
1.	Composting	• Composting minimises or avoids the GHG emissions from the anaerobic decomposition of organic waste • Composting increases the design life of other waste management facilities • The use of Composting reduces the dependency on chemical fertilisers for agricultural operations • Composting may be used to revitalise vegetation habitats and add life to marginal, impoverished soils and wastelands.	• Compost quality standards (SWM Rules, 2016 and FCO series) are becoming increasingly stringent • The long-term benefits of soil conditioning properties of compost are not adequately appreciated by the farmers and other stakeholders.
2.	Anaerobic Digestion	• It sanitizes the feedstock/ waste which is put through it, as long as the temperature is held above a required temperature for a pre-defined time period • Provides for efficient resource recovery and conservation of non-renewable energy sources • The process produces some carbon dioxide in addition to methane which can be purified and sold as a valuable product.	• When carried out at a commercial scale, it requires a high investment • Does not convert as large a proportion of the carbon in the biomass to biogas as can be achieved using gasification • The digestion output contains ammonia which needs care to prevent ammonia gas from causing air pollution.
3.	Production of Refuse Derived Fuel	• RDF is one of the alternatives and renewable resources of fuel which is derived from municipal waste • The emission characteristics of RDF are superior compared to that of coal with fewer emissions of pollutants like NOx, SOx, CO and CO2.	• A considerable cost is associated with the pre-processing to recover the fuel fraction • Unit yield of energy (i.e., kJ per kg of MSW) in the case of RDF is less than that of the parent MSW.
4.	Incineration	• Efficient use of space • Elimination of groundwater contamination • Lower carbon footprint.	• High incineration plant costs • Emissions of toxic pollutants like CO_2 (carbon dioxide), N_2O (nitrous oxide), NOx (oxides of

[34] Extract from Municipal Solid Waste Management Manual – II issued by MoHUA.

			nitrogen) and NH_3 (ammonia) etc.
5.	Pyrolysis	• Unlike traditional incineration plants, a pyrolysis plant can be located close to the point of generation and does not produce any harmful dioxins • Pyrolysis plants are efficient at converting waste into useful products, such as synthetic oil for fuel. Unlike incinerators, which burn waste at extreme temperatures, a pyrolysis plant uses a lower temperature process that results in less noxious by-products and reduced carbon emissions.	• The process is expensive therefore uses in big companies which have large amounts of waste.
6.	Gasification	• This process can be widely used on industrial scales for the generation of electricity from fossil fuels • A wide variety of biomass and waste-derived feedstock can be gasifier, including wood waste, plastics, aluminium, municipal solid waste (MSW), agricultural and industrial wastes, sewage sludge and crop residues • The operating costs of a gasification power plant are lower than conventional coal-fired plants and require less pollution control equipment.	• High calorific value waste, which may otherwise be processed in more sustainable processes, is required as feedstock.
7.	Plasma Gasification	• Safe means to destroy both medical and many other hazardous wastes • Gasification with starved combustion and rapid quenching of syngas from elevated temperatures can avoid the production of dioxins and furans that are common to incinerators • Air emissions can be cleaner than landfills and similar to that of incinerators.	• During plasma gasification, tars, heavy metals, halogens, and alkaline compounds are released within the product gas and can cause environmental and operational problems.

Chapter 3. Audit of Municipal Solid Waste Management by C&AG of India

Waste is a continually growing problem, globally, regionally and locally. Considering the nature of the Waste Management Industry and the pace at which it has grown over the past decade, the Comptroller and Auditor General of India (C&AG) has conducted several performance as well as compliance audits of this sector. These audits broadly examined the role of agencies/ departments in assessment of different kinds of waste and their risk to the environment and health, adequacy of policy and planning for waste management including waste minimisation and waste reduction, role segregation and coordination between various agencies, monitoring and follow-up etc.

Figure 3.1: Audit reports by C&AG on waste management

Performance Audit Report "Management of Waste in India (2008)" for the period from 2002-2003 to 2006-2007[35] revealed significant systemic and compliance related deficiencies. There was an absence of a single body taking ownership of waste issues in India. Further, there was no clear identification of bodies for monitoring the waste rules at the Central Government level, which caused a mismatch/gap in responsibility as well as accountability which led to the rules for the management of waste being rendered ineffective. It also highlighted that the municipalities were not ensuring the compliance to municipal solid waste rules effectively and there were negligible segregation of waste after its collection. Waste processing facilities and scientific landfills were almost non-existent and as a result, open dumping was the most common option for waste disposal. Apart from these, municipalities did not adequately plan for closing of dumpsites and had not identified areas for landfills for the scientific disposal of waste. In the absence of landfills, open dumping of waste was continued leading to harmful effects on health and environment. It was observed that the hospitals/ private operators were running waste disposal facilities without authorisation and segregation of biomedical waste. The waste treatment/disposal infrastructure created in the most of the states was also inadequate. Audit observed ineffective enforcement of the plastic waste rules rule by District Commissioners/District Magistrates and Pollution Control Boards in states. The audit covered 24 states including 56 municipalities, 180 hospitals, concerned pollution control boards/ committees, urban development department etc. At the Central level, Ministry of Environment and Forest and Central Pollution Control Board were covered.

Similar initiatives have been undertaken to review the aspects of waste management in different sectors, locations and operations of government enterprises. Various audit reports[4] the issue of waste management in Indian Railways. Recently, a Performance Audit on Waste Management in Indian Railways of 2022 (Report No.16) examined the issue of managing waste at stations, coaching depots, maintenance & production units and hospitals including adherence to the directives of National Green Tribunal (NGT) in their various orders.

C&AGs reports pertaining to waste management for different states have also broadly highlighted issues in planning and implementation of MSW rules/guidelines including mismanagement of different types of solid waste such as E-waste, plastic waste, bio-medical waste etc. Some broad areas covered in audit and associated issues noticed during audit of

[35] Report No. PA 14 of 2008 for the Period ended March 2007 - Management of Waste in India (https://cag.gov.in/cag_old/content/report-no-pa-14-2008-period-ended-march-2007-management-waste-india)

waste management for the states namely; Karnataka[36], Goa[37], Rajasthan[38], Manipur[39] and Himachal Pradesh[40] are discussed in succeeding paragraphs:

3.1 Planning

Municipalities are vested with major responsibilities for SWM in urban centres for planning and implementation of rules/guidelines. While the onus of providing MSWM services in urban areas lies with the ULBs, Central and State governments have a significant role to play in defining the framework within which service providers can be planned and executed by ULBs. Audit have also highlighted deficiencies in policy. Deficiencies in planning and redundant data related issues have also been highlighted. It has been reported that many municipal authorities neither prepared short-term plans nor long-term plans, which deprived the ULBs to adopt a systematic approach to SWM. In the absence of these plans, the planning and selection of infrastructure projects were to a large extent, driven by perceived availability of funds rather than a need-based analysis. Agencies and departments (ULBs, Directorate of Local Bodies, SPCB, RDD and PRD) did not assess quantum of generation of solid waste, plastic waste and e-waste or such waste likely to be generated in future. Audit brought out the significant role of informal sector such as waste pickers/collectors in waste segregation to bring it systematically within waste management framework and assess impact on their health and wellbeing.

3.2 Implementation and Monitoring

The authorities engaged in MSW activities are required to improve the efficiency of their MSW collection and transportation systems to ensure that the minimum quantity of waste reaches the processing facility or disposal site on a regular basis. Audit noticed various instances of lacunae, lapses and inefficiency in implementation of waste management strategy as highlighted below:

- Dumping of waste at landfills due to non-collection and non-processing of total waste by the ULBs with potential risk for health and environment.
- Issues in door to door collection of MSW and gap between waste generated and collected by ULBs

[36] https://cag.gov.in/cag_old/sites/default/files/audit_report_files/Report_No_4_of_2018_Performance_Audit_of_Solid_Waste_Management_in_Urban_Local_Bodies_Government_of_Karnataka.pdf

[37] https://cag.gov.in/en/audit-report/download/57673 (Report No. 2 of the year 2019 of Government of Goa for the year ended 31st March 2018)

[38] https://cag.gov.in/en/audit-report/download/46715 (Report no 2 of the year 2018 of Government of Rajasthan for the year ended 31st March, 2017)

[39] https://cag.gov.in/en/audit-report/download/87123(Report no 2 of the year 2019 of Government of Manipur for the year ended 31st March, 2018)

[40] https://cag.gov.in/en/audit-report/download/114173 (Report no 2 of the year 2021 of Government of Himachal Pradesh for the year ended 31st March, 2019)

- Improper segregation of waste by the ULBs and associated issues
- Burning of waste and burying in the sand.
- Lack of infrastructure such as storage facility, segregation sheds and composting pits to recycle the biodegradable component into manure and waste disposal facility
- Issues in transportation of waste and associated hazards
- Non-identification of landfill sites resulting in contamination of surface and ground water near to habitant areas.
- Issues in authorisation for running waste disposal facility, slaughter houses,
- Non-promotion of alternate usage of waste such as plastic waste for use in laying of roads.
- Inadequate precautions or lack of proper safety measure (gloves, gum boots face masks etc.,) for waste puckers/collectors.
- Delays and deficiencies in submission of Annual reports by ULBs to SPCBs.
- Issues in collection of user charges prescribed and their proper accounting.
- Shortfalls in conducting regular meeting with local resident welfare associations/NGOs to ensure community participation.
- Issues in selection of landfill with regard to distance from habitation clusters, water bodies, monuments, wetlands etc. with associated parameters for development, operation and maintenance of landfill sites.
- Deficiencies in financial sustainability of the ULBs through imposition of taxes and fees.
- Shortfalls in complaint redressal mechanism against the defaulting waste generators.

3.3 Mismanagement

Special waste including domestic hazardous waste comprises any solid waste or a combination of solid wastes that require special handling and disposal because of its quantity, concentration, physical and chemical characteristics, or biological properties, in order to protect human health, as well as the environment and to exploit its potential for recycling.

Rules notified by the MoEFCC for different types of special wastes including domestic hazardous waste aim at their environmentally sound management. Audits have pointed out numerous instances of improper segregation of waste leading to the mixing of MSW with plastic waste, Bio-medical waste, e-waste and slaughterhouse waste leading to environmental and health hazards.

3.4 Audit Recommendations and Summing up

With a view to promote proper municipal solid waste management, review of waste management strategy involving all stakeholders, better coordination, proper roadmap and timely funding of various initiatives have been recommended in audits. The details of some of the audits conducted by C&AG of India on waste management are given in **Annexure-A**. These include putting in place proper action plan as per relevant rules and guidelines, DPRs on a cluster basis, strengthening waste collection system, better information systems, wider publicity and awareness campaigns including meetings with Housing Associations and NGOs, comprehensive database, etc. Besides comprehensive assessment of the quantity of various waste and reliable data regarding population, geographical areas, sectors would aid in policy-making. There should be a proper mechanism for levying penalty at the state/ULB level for the violation of waste management rules. Period studies for evaluation/review of waste management strategy can help in timely course correction and modifications based on the outcomes of the findings. Strengthened strategy on Information, Education and Communications to promote waste prevention and waste minimization especially through reduction, reuse and recycling would aid in proper waste management and sustainable production and consumption in line with the Agenda 2030 for transforming the world.

Chapter -4 Good practices followed by Indian Cities to deal with Municipal Solid Waste

After the launch of Swachh Bharat Mission, the efforts for sustainable waste management has been strengthened in all States/UTs. It is important that we upheld the momentum gained through initiatives taken under SBM to achieve the targets as envisaged. The comprehensive knowledge resource showcasing best practices of waste management sector will help and guide cities to develop their waste management plans with greater efficiency.

Therefore, the best practices in the areas of waste management in some of the states have been studied and incorporated in the publication get to insights about recent trends and technologies about the sector.

4.1 Decentralized waste management in Allepey (Allapuzha) in State of Kerala

Alappuzha a city located in Kerala successfully implemented decentralized solid waste management system, and it is widely known as 'Alappuzha Model'. The Alappuzha Municipal Council (AMC) has distinguished itself by its success in source-level segregation coupled with decentralised waste management. Transition to decentralized solid waste management was not a mere bureaucratic process. It was a determined effort to change people's waste management habits and to treat the waste at source. Alappuzha model of waste management has since then considered as a replicable model of decentralized solid waste management. In 2016, Centre for Science and Environment, New Delhi considered Alappuzha as a clean city. By reducing pollution, the spread of water-borne diseases has been controlled and the overall health of the community has improved in Alappuzha. For its sustainable waste management practices, Alappuzha received recognition from the United Nations Environment Programme in 2017[41].

4.1.1 How the system has worked

To begin with, AMC targeted unnecessary generation of waste at source. Fines and penalties were implemented to make citizens careful about their waste practices. Awareness programmes have been launched to both reduce and segregate waste at the household and institutional levels. Door-to-door collection of waste was started in all wards with the help of a women-run self-help group (SHG) called **Haritha Karma Sena.** The SHG only collects non-biodegradable waste while biodegradable waste is handed over to the community aerobic bins by people who

[41] Information available on website of Allapuzha municipality

don't have bins in their households. Non-biodegradable waste is collected once a month from households and once a week from commercial establishments.

Non-biodegradable waste is collected at mini-material collection facilities (MCFs). From the MCFs, the waste goes to four centralised material recovery facilities (MRFs). There are three plastic shredding units and one baling unit to process non-biodegradable waste. At the MRFs, Haritha Karma Sena members segregate plastics into eight categories and sell recyclables to local women's group engaged in recycling. There are adequate aerobic composting units with multiple bins where people can deposit their biodegradable waste. At full capacity, the units are able to treat about 80 per cent of the biodegradable waste generated in Alapuzzha.

4.1.2 Good practices and lessons learnt

- **Creating awareness about source segregation**
- **Involving the community**
- **Importance of leadership and organisation:** During this whole evolution**,** all project originated under the leadership and guidance of the local government. The initial push provided by the authorities was much needed to get the process off the ground.

4.2 Scientific Solid Waste Management in Bobbili in the State of Andhra Pradesh[42]

Bobbili is a historic town in the district Vizianagaram, Andhra Pradesh. There has been a ban on plastic bags and pouches in the town for more than 10 years back, moreover the town's crowning achievement is its biodegradable waste processing as by combining home composting with windrow, vermi-composting and through biogas plant, the town manages to process all of the biodegradable waste it generates.

Today, Bobbili is one of the towns in India to have such a scientific solid waste management system and 100 per cent collection of garbage in place. It has also won the Prayavaron Mitra[43] Award from the State Government besides several other environment awards.

4.2.1 How the system has worked

All this have been possible due to a scientific and sustainable solid waste management system in Bobili. Initially, an Information, Education and Communication (IEC) programme was

[42] Extract of information given on the website of Commissioner and Director of Municipal Administration, AP
[43] https://timesofindia.indiatimes.com/city/visakhapatnam/bobbili-town-an-inspiring-lesson-in-smart-waste-management/articleshow/53202971.cms

recognised to be a key tool to achieve this objective. The public IEC programme consisted of street plays and stage shows organised as per local cultural practices.

Within no time, the municipality had a working model to handle various types of waste. A route map system was created to cover every house under door-to-door collection of segregated waste. Penalties were imposed on littering and failure to segregate. The town took several steps to eliminate the use of plastic bottles and sachets. Every shop is provided with two bins – for non-biodegradable and biodegradable waste – and it is the responsibility of shop owners to ensure that their customers use the bins appropriately. Only biodegradable cups are allowed in coffee and tea cafes.

Within a month of the introduction of the route map system, the staff achieved almost 100 per cent door-to-door waste collection. Efficient collection made it easy for the city to transport garbage to the dumping yard. By integrating Internet of Things (IoT) and Information and Communication Technology tools, the State Government launched a Real Time Monitoring System – an analytical dashboard that has set a benchmark in micro-planning with pinpoint details of source segregation, gate-to-gate collection, collection routes, transfer points and weight of the waste before it is loaded into trucks.

Under the Real Time Monitoring System, every household and apartment, termed a 'gate', is given a radio frequency identification (RFID) tag. Sanitary workers carry an electronic scanner and share real-time information about household waste with the city-wide monitoring system. Waste collected from each micro-pocket is digitally measured. Garbage trucks are fitted with GPS devices to track their movement. Attendance of sanitary workers is monitored by an Aadhar-based facial recognition system.

4.2.2 Good practices and lessons learnt[44]

- **Creating awareness in community**
- **Involving the community**: Plenty of local workers have been hired to complete the whole process of ccomposting and generation of energy through bio gas.
- **Importance of leadership and organisation**

[44] https://www.niti.gov.in/sites/default/files/2021-12/Waste-Wise-Cities.pdf

4.3 4R Principle for disposal of waste in Pune City – Decentralized Biogas Plants

In extension to 3R Principle (Reduce, Reuse and Recycle), in the present scenario, the area of discussion is 4R Principle, which is the widely used in SWM and termed as reduce, reuse, recycle & recover. Most of the materials thrown in the garbage can be used & processed in ways other than being destroyed and such the process is called as recover. In order to decrease the environmental and health effects associated with landfilling, waste management is now a days moving away from disposal and towards waste prevention, reuse, recycling and energy recovery.

Poor [45]solid waste management is a threat to public health and causes a range of external costs. Mixed wastes from municipalities are often landfilled. Landfill deposits pose the risk of uncontrolled air, soil and water pollution. Left to degrade naturally in landfill sites, organic wastes from households and municipalities have very high methane production potential; thus, have a negative impact on the environment.

4.3.1 Biogas as Initiative - Solution to food waste with the bonus of eco-fuel[46]

The Pune Municipal Corp (PMC), has, in many ways, become the model corporation when it comes to disposal of waste through multiple solutions that follow the 4R principle. A part of this is to treat food waste generated by bulk users separately, not only to reduce and recycle waste but to recover valuable energy by converting it into valuable bio-fuel.

[45] https://www.iwmi.cgiar.org/Publications/Books/PDF/resource_recovery_from_waste-222-231.pdf
[46] https://www.pmc.gov.in/en/biogas-initiative

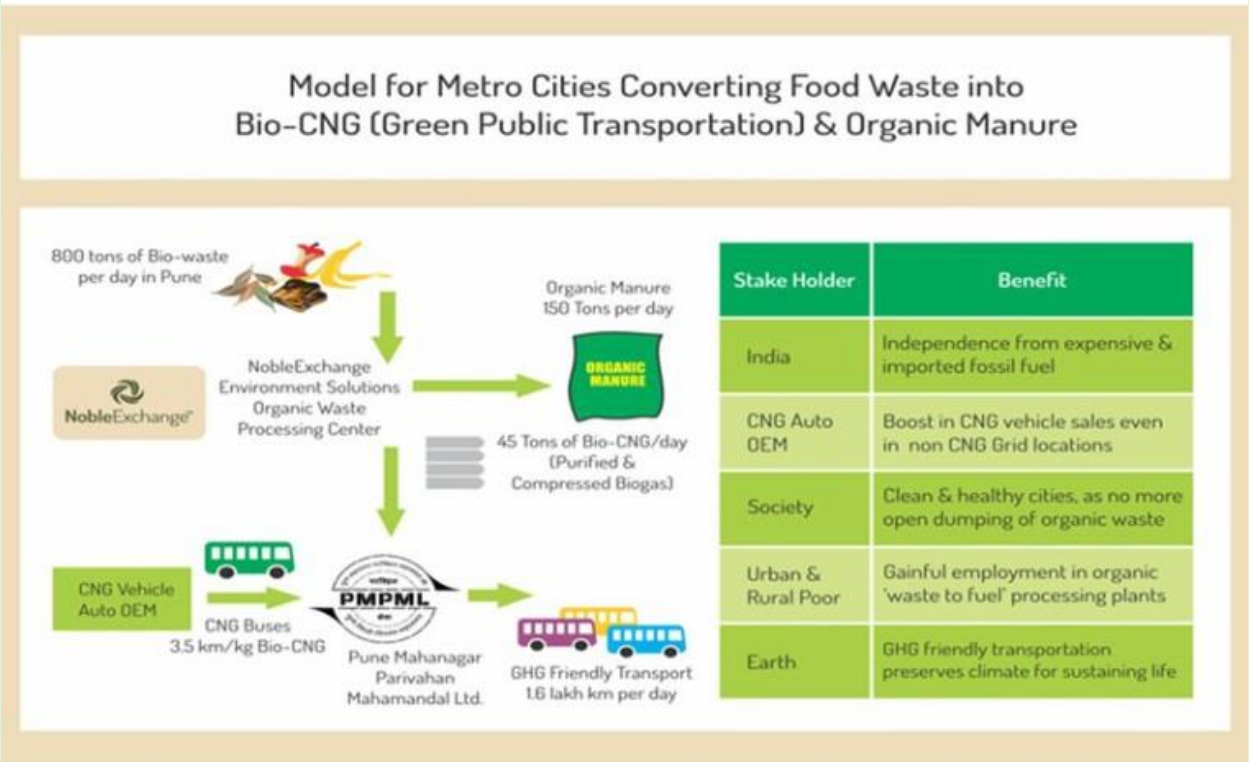

Figure 4.1: Model of Bio-CNG (Source- Pune Municipal Council)

A company (NEX), which is funded by Adar Poonawala's Clean City Movement supported by the promoters of the Serum Institute is the implementation partner for this project.

The unique features of the environmentally efficient the NEX waste processing plant include odourless and noiseless operation with zero discharge, which is essentially based on the anaerobic digestion system with water-based cleaning, scrubbing, and compression system that converts the organic waste slurry into compressed biogas (CBG). By-products generated from the process will be organic fertilizers that replace chemical fertilizers for farming. Compressed Biogas (CBG) produced at the processing plant will be marketed to institutional clients to replace conventional energy - LPG, diesel etc. By-products generated from the process will be organic fertilizers that replace chemical fertilizers for farming. Compressed Biogas (CBG) produced at the processing plant will be marketed to institutional clients to replace conventional energy - LPG, diesel etc.

4.4 Circular Economy Concept in Indore

Indore[47], an education hub and the commercial capital of Madhya Pradesh has now earned the 5-star garbage-free city tag. Indore has been ranked the cleanest city of India in Swacch

[47] NITI Ayog report on best practices in Solid Waste Management.

Survekshan surveys since 2017[48]. The city is not only open defecation free but has also earned the first Water Plus Certification in the country.

Considering the fact that Indore was rated 25th in the first Swachh Survekshan survey of 2016 and turned itself around to achieve first rank since then every year.

The things started to change in December 2015 when Indore Municipal Corporation (IMC)[49] started door-to-door collection as a pilot project in Wards 42 and 71. IMC also undertook awareness programmes in these wards to motivate residents to segregate their waste into biodegradable and non-biodegradable fractions. It was observed that people were ready to do their part as long as they were assured of regular and reliable garbage collection services. In February 2016, door-to-door collection was extended to ten wards and by October 2016, IMC started door-to-door collection of garbage in the entire city, along with a campaign to promote source segregation. Initially, a two-bin system was used for segregation as per the guidelines of Swachh Bharat Mission – green bins for biodegradable waste and blue bins for non-biodegradable waste. In 2017, Indore adopted the use of separate bins for sanitary and hazardous waste, as per the new Swachh Survekshan toolkit. Presently, the city is segregating its waste into six categories: 1. Biodegradable, 2. Non-biodegradable (excluding plastic), 3. Plastic, 4. Sanitary, 5. Domestic hazardous and 6. Electronic. IMC had originally installed two sets of litter bins across the entire city. During the pandemic, it also installed a set of third bins (yellow) in which people could put their masks and gloves.

The success of Indore's waste management derives first and foremost from its success in achieving 100 per cent segregation of waste at source. It is apparent from the success story of Indore that Door-to-door collection of segregated waste is possible in every city, town and village of India provided that the local governing bodies are committed to it.

4.4.1 Circular economy in Indore

Recently in February-2022[50], the 'lighthouse plant' has been set up by IMC and Indo Enviro Integrated Solutions Limited (IEISL) under the Public-Private Partnership (PPP) model. It is helping achieve the twin objectives of zero-waste and circular economy under waste-to-wealth initiative. Indore's quality of wet waste is one of the best in the world, which prompted the private partners to participate in the PPP bid for setting set up of bio-CNG plant in the city at

[48] Yearly Swachta Sarvekshan done by MoHUA
[49] Extract of information available on website of Indore Municipality
[50] https://www.outlookindia.com/national/waste-to-wealth-pm-modi-to-inaugurate-mega-bio-cng-plant-in-indore-news-182860

their own cost. This bio-CNG plant will produce 17 to 18 metric tons of Compressed Bio-Gas (CBG) along with 100 MT per day of high-quality organic manure. Indo Enviro Integrated Solutions Limited (IEISL), the private partner which has made 100 per cent capital investment for the project, will also bear the operation and maintenance cost for the entire concessional period of 20 years. It is based on zero-landfill models.

Accruing the benefits of the PPP Model, IMC will also get annual royalty of Rs. 2.52 crore from IEISL. Further, IMC will purchase a minimum 50 per cent quantity of Bio-CNG produced at the plant at the rate of Rs. 5/-, which is less than the prevailing market price of CNG used for running the city buses.

The project has some unique features such as a fully automated pre-treatment unit and separation hammer mill technology for the preparation of bio-slurry feed to run digesters. Besides, the anaerobic digesters, mounted with agitators, work on Continuous Stirred Tank Reactor (CSTR) principle. Also, Vacuum Pressure Swing Adsorption (VPSA) technology has been used to ensure high-quality recovery of bio-CNG fuel from raw biogas.

4.5 Municipal Solid Waste management in Surat[51]

Surat is the nerve centre of economic activity in Gujarat and also a hub of both small-and large-scale industries. The rapid population growth caused several management problems for Surat Municipal Corporation, which is responsible for provision and maintenance of the entire range of civic infrastructure services in the city (including sanitation and drainage facilities, and solid waste collection and disposal). The lack of basic services and infrastructure led to a plague outbreak in 1994, which claimed several lives. The major cause was considered to be ineffective waste management, which led to the blockage of storm-water drains resulting in flooding of the fringe areas of the city.

The governance of the city changed significantly after the outbreak. Regular sweeping of streets and garbage collection has become a hallmark of Surat Municipal Corporation (SMC). A centralised and then a decentralised process of waste collection and disposal were implemented within six months of the outbreak. Surat has achieved 100 per cent door-to-door garbage collection as well as source segregation. In fact, the city also has a mechanism in place for segregating domestic hazardous and plastic waste. All of the city's waste is treated efficiently in decentralised or centralised waste processing plants. Surat was ranked the second

[51] https://www.niti.gov.in/sites/default/files/2021-12/Waste-Wise-Cities.pdf

cleanest city in India by Swachh Survekshan 2020. It has also received a 5-star garbage-free city tag for its extraordinary management of solid waste.

The corporation has been able to successfully remediate 25 lakh tonne of legacy waste at the Khajod dumpsite through bio-capping.

4.5.1 How the system has worked

The awareness campaign Surat-Khubsurat realized the citizens a sense of belonging to their city. The initiative brought significant behavioural change among the public. There were launched several initiatives to promote cleanliness and hygiene in their day-to-day lives.

Solid waste in Surat can be broadly divided into eight major categories on the basis of source of generation: domestic waste, biomedical waste, commercial waste, hotel waste, construction waste, textile waste, dead animal and industrial waste.

4.5.2 Good practices and lessons learnt

SMC has designated eight locations for collection of plastic waste. Segregated valuable plastic waste is collected from households and streets with the help of NGOs, rag-pickers, plastic collection centres etc. Non-segregated plastic waste collected by door-to-door vehicles is transported to segregation stations for further processing. Recovered plastic from this facility is send to a centralised plastic-waste-processing.

Waste is treated as an asset that brings economic benefit. A large part of waste goes towards refuse-derived fuel but the part that is recycled is converted to money. Success was achieved with the vigorous cleanliness drive through regular garbage collection and sweeping of roads and other public areas by the municipal corporation

To maintain cleanliness and community-level participation in SWM, payments at the rate of 60 paise and 65 paise per sq. m respectively are made to residential and non-residential societies. The minimum amount payable to societies is Rs 1,200 per month. Societies are required to arrange for sweepers and sanitary equipment on their own while the SMC pays for consumable items such as insecticides. SMC makes payments to societies based on production of a completion certificate, duly signed by the president of the society on a monthly basis. Societies are required to make an agreement with SMC to provide regular waste management services in their designated areas. More than 600 societies have been benefit under this scheme. About 15,000 people are indirectly employed from the informal sectors to transform waste material into usable products. This has created the opportunity of regular assured income and sustainable livelihood.

Chapter - 5 Research Contributions from the Energy and Resources Institute (TERI) and International Centre for Environment Audit and Sustainable Development (iCED)

The subject of environment and sustainability are crosscutting and continuous evolving with continuous research taking place in these areas. While many areas are supported by policy frameworks, there are recurring issues and challenges affecting proper implementation of rules and regulations. In many other areas, the available solutions reflect lack of consensus among different stakeholders. A well informed research input therefore becomes imperative to promote sound principles of waste management and aid in evolving proper governance framework for this sector.

5.1 Research contributions from TERI

TERI, an independent non-profit organization has capabilities in research, policy, consultancy, and implementation. It has multi-disciplinary expertise in the areas of energy, environment, climate change, resource efficiency, and sustainability. TERI's mission is to usher in transitions to a cleaner and more sustainable future through conservation and efficient use of the earth's resources and develop innovative ways of minimizing waste, and recycling and reusing resources across a product's value chain.

TERI works closely with utilities, regulatory commissions, government agencies, corporate sector and bilateral and multilateral organizations including the World Bank, Asian Development Bank, Japan Bank for International Cooperation, UK Department for International Development, United Nations, German Technical Cooperation, Research Council of Norway and U.S. Agency for International Development among many others.

TERI has been involved in the past with various government bodies at national, state, and local level to incorporate circular economy principals in hard to abate sectors and various waste streams. TERI takes a strategic approach to waste challenges and has considerable experience designing and initiating programmes to mitigate the waste sector's environmental and health impacts in India and abroad, including climate change impacts. TERI has developed solutions for providing sustainable and economical waste management in the country. It has supported programmes for facilitation of good governance and ensuring universal access to improved environmental services namely solid waste, waste water management, improved sanitation. Waste streams addressed include municipal solid waste, e-waste, industrial waste, construction

and demolition, liquid waste stream, overall plastic pollution in different waste streams and its linkages with marine pollution.

TERI's project on implementing waste NAMA (Nationally appropriate mitigation actions) focuses on evaluation and implementation of low carbon measures to reduce emissions from the solid waste sector in Goa and Varanasi by reducing the amount of waste landfilled under precarious conditions. The project determines feasibility of relevant waste management practices such as effective source segregation and establishment or strengthening of existing Material Recovery Facility to house processes including micro composting and bio-methanation among other waste processing measures. The project also explores possibilities of implementing technologies such as composting, anaerobic digestion, co-processing of solid waste and other feasible technological options. In wastewater management, TERI's patented technology has been used to provide end-to-end treatment of municipal and industrial wastewater streams having high colour, chemical oxygen demand, biochemical oxygen demand, total organic carbon dissolved organics, non-biodegradable, and persistent organic pollutants. The technology development and dissemination is in agreement with M/s Perfact Researchers Private Limited to promote TERI's wastewater treatment technology. Also, the project titled Local Treatment of Urban Sewage Streams for Healthy Reuse (LOTUShr) demonstrates novel holistic waste-water management approach for the recovery of water, energy and nutrients from urban wastewater, which includes anaerobic digestions, algae photo-bioreactors and wetlands. The required treatment and reclamation steps will be determined by the water quality needed for safe and healthy reuse in households, industry and urban agriculture with special attention on pathogen removal and removing conventional and emerging pollutants. LOTUShr will lead to development of reliable technologies, tools, models and approaches for local stakeholders enabling market development for water reuse strategies and solutions for other Indian Mega Cities.

TERI has played a major role in the management of industrial sludge, oily sludge, and faecal sludge. TERI's Oilzapper technology is used by petroleum industries (ONGC, IOCL, HPCL, BPCL, Oil India Limited, Tata Power, BG Exploration Limited, and Reliance Petroleum) across India for sustainable solution for bioremediation of oil spills and oily sludge contaminated sites in a cost-effective manner. The Kuwait Oil Company (KOC) has used the technology for the bioremediation of 2.8 million tonne of oil-contaminated soil. TERI has also come out with a policy brief on Fecal Sludge Management in India looking at current practices,

policies, FSM as an entrepreneurship model, adoption of FSM at city-level, and short and medium-term recommendations for uptake of FSM. For industrial sludge management, TERI has incorporated principles of circular economy in the sugar industry by using bagasse fly ash as a cost-effective filter for membrane bioreactor (MBR) for wastewater treatment.

For organic waste management, TERI's innovative technology on enhanced acidification and methanation (TEAM) technology was installed as a first-of-its-kind bio-methanation plant in Udaipur city supported by the Udaipur Municipal Corporation after which the plant was put up in West Bengal as well. TERI has installed many bio-methanation plants for municipal solid waste and industrial waste and it has also performed audit and feasibility study of these plants for performance assessment, gap identification, improvement and conducted training and capacity building workshops for municipalities, plant operators, project developers etc. Currently, TERI is developing standards and guidelines for large scale biogas plants in India and has also estimated the biogas generation potential from co-digestion of sewage sludge and rice straw.

TERI has worked in fostering circular economy and resource efficiency in various sectors. As part of EU-REI (Resource Efficiency Initiative) developed and launched Strategy for Fostering Resource Efficiency and Circular Economy in Goa[52], which presents an overall state-level action plan to mainstream resource efficiency and circular economy and foster sustainable management of resources in the state. An Urban Services Environmental Rating System (USERS) developed by TERI is a performance measurement system for urban local bodies in Delhi and Kanpur for improving their basic services like water supply, sewerage and solid waste management. TERI has audited the MSW management activities for urban local bodies, done audits on various STPs, waste-to-energy plants and conducted energy audits to help identify gaps in system, and determine ways of improvement. TERI has been the pioneer organisation to conduct municipal solid waste audits and help ULBs enhance their efficiencies and effectiveness in the waste sector. TERI's staff possesses rich and varied experience in the waste and organic waste sector, who have been providing assistance on a range of activities to public, private, and institutional clients.

TERI is creating technologies and solutions to minimize waste generation and convert waste into useful products including refuse derive fuel (RDF), compost etc. TERI works towards

[52] https://www.teriin.org/sites/default/files/files/strategy-fostering-RE-CE-Goa.pdf

initiatives to promote circular economy through source segregation at individual level and via adoption of resource efficient and cleaner production technologies in industries to maximize resource recovery and recycling for landfill-free cities. TERI conducts material flow and life cycle assessments to determine environmental impacts and provides mitigation solutions that contribute to resource efficiency and circular economy.

In recent times, TERI has worked with support of UNEP to develop marine litter action plan for the country addressing both waste disposed on land and waste disposal in water bodies finally reaching the coastal waters. The focus of exercise was mainly on plastic waste which is significant part of marine debris.

5.2 Research contributions from iCED

International Centre for Environment Audit and Sustainable Development (iCED) promotes knowledge sharing and research in the area of environment and sustainable development issues. It also undertakes various activities as per role/s assigned to it on behalf of Supreme Audit Institution of India for Working Group on Environmental Auditing (WGEA) under the International Organization of Supreme Audit Institution (INTOSAI). Research activities have gained momentum through engagement of interns, young professionals and research associates at iCED, covering the issue of Plastic waste, E-Waste, Hazardous waste and Municipal Solid Waste besides other areas. Broad highlights of these study reports/ case studies are mentioned in the following paragraphs:

5.2.1 Plastic Waste

The study provides an overview of the implementation of plastic waste management rules in Jaipur city. Based on estimate made by Central Pollution Control Board (CPCB), it highlighted that approximately 9.4 MT plastic waste is generated in India per annum as of 2017-18, out of which only 5.6 MT constituting 60 percent of total plastic waste generated is recycled and 3.8 MT are left uncollected or littered[53]. It further stressed that there is constant increase in plastics waste generation chiefly due to single use plastic as 50 percent of plastic is discarded as waste after single use.

The intern gathered the data through field visits and indicated lapses and deficiencies in various stages of waste management. Non-segregation of plastic waste at source, primarily due to lack of awareness among the common people as well as municipal workers was highlighted as one

[53] Source: UNIDO Report- Recycling of Plastics in Indian perspective by Dr. Smita Mohanty

of the major factor affecting proper plastic waste management. Use of old, poorly maintained vehicles and their lower frequencies restrict the efficiency of collection/transportation.

Waste was not being segregated and processed at any transfer station, due to a lack of sorting and processing facilities. All waste disposal sites did not have waste processing facility and waste was lying in open areas or were directly disposed of and dumped at sites. Further due to poor waste collection the plant was not running to its full capacity.

At most of the transfer stations, the segregated plastic waste was weighed manually affecting accuracy in measurement of weight of the waste and reliability of related data. Lack of pollution monitoring equipment and improper implementation of safety provisions were noticed.

It underlined other issues and lapses in execution of activities as per extant rules/ guidelines such as Extended Producer Responsibility (EPR)[54] policy by State Pollution Control Board, coordination among agencies, technological approach and infrastructure requirements. It also noted lack of provision for waste pickers in waste management sector.

The study recommended the need to bring the circular economy concept to plastic products and steps to shift to non-plastic items made from bio-based raw materials which are biodegradable and compostable. More research and development work on the integration of mechanical, chemical and other evolving recycling techniques especially involving any biological activity recommended to speed up true circularity in this sector.

5.2.2 Electronic Waste or E-Waste

Unused electronics lie unattended in homes, offices and warehouses until they are eventually mixed with regular waste due to uncertainty about how to manage it, which can be hazardous and have the potential to severely impact human health and the environment if they are not handled properly. During the surveys conducted in the study, it was observed that 23 per cent of the respondent were keeping the E-waste at home mainly due to the absence of a proper E-waste collection mechanism as no methods/ procedure for channelizing E-waste to authorized recyclers/ dismantlers has been notified. The general schemes for collection of E-waste under the EPR such as through dealers, collection centres, PRO, Buy-back arrangement, Exchange Scheme, Deposit Refund System, etc were not in existence. It was also found that there were no specific collection points assigned for the collection of E-waste. There was less awareness among consumers about the EPR (Extended Producer Responsibility) and e waste is channelized through informal sectors having environmental implications. As per the survey conducted, 57 per cent of the respondent sold their E-waste to *Kabadiwalas*. About 63 per cent

[54] The responsibility of a producer for the environmentally sound management of the product until the end of its life.

of the respondents during the survey conducted to determine the level of public awareness were unaware of E-waste rules and their associated problems. Awareness of E-waste has been gradually rising among the consumers but due to the lack of sincere efforts made by the formal sector, most of the E-waste generated ends up within the informal sector. There is a need for stringent penal provisions and robust monitoring mechanisms to deal with E-waste

For enforcing EPR, such regulations as "Take-back with Recycling targets" practised by South Korea can be incorporated for better management of E-waste. Suitable penal provisions may be incorporated in these Rules in line with the Section 15 of the Environment (Protection) Act, 1986 including imprisonment or with a fine which may extend to one lakh rupees, or with both in the event of contraventions of the provisions of the EPA.

5.2.3 Industrial Hazardous Waste Management

A study was done to assess the locational compliance of seven selective common Treatment, Storage and Disposal Facility (TSDFs) sites in Rajasthan and Gujrat in terms of their distance from highway, river and vegetation as per CPCB site selection guidelines using the GIS tool, Google Earth Pro. It found that three sites were not in compliance with stipulated guidelines and recommended further detail to assess their implications and associated risks.

5.2.4 Municipal Solid Waste

This study highlight issues associated with the management of Municipal Solid Waste in three selected cities namely Indore, Surat and Jaipur. It underlines various management practices being undertaken by the management and enforcement authorities in these cities for effective and sustainable treatment of MSW generated. The study also shows that waste segregation at the door-to-door collection level is the most crucial for the proper management of Municipal Solid Waste. Indore and Surat cities have an extremely efficient waste segregation mechanism which has enabled them to gain top rankings in the past "Swacch Sarvekshan" surveys. However, Jaipur city found facing challenges in implementing an efficient waste management mechanism to compete with other cities.

Based on the method of Causal Loop Diagrams (CLDs), the study identifies the basic problem i.e. improper waste collection and segregation and for exploring possible solutions. Some of the major challenges for ineffective segregation of waste are Public Awareness, Low Budget Allocation, Steering motivation to segregate waste through monetary incentives, and effective implementation of a penalization mechanism for segregation.

For suggesting possible solutions to the problem of segregation of waste at source, the typology suggested by Arie Frieberg (Freiberg, 2010) in his toolkit is referred. Classifying the probable solutions under Carrot & Command-and-Control typology is also attempted. These involve the manipulation of the production, allocation, or use of material resources such as money or property, in all its forms. Forms of economic regulation include taxes, subsidies and tradable permit schemes. Each of these can be used to promote as well as restrict or even prevent certain activities. Taxes, charges and levies can be used to influence the behaviour of individuals.

Chapter - 6 Recommendations and Proposed Strategies

Considering a country like India which is an emerging economy (presently fifth largest economy) and aspiring to be developed economy, increasing trend towards urbanisation and industrialization is expected to gain momentum in coming decades. With increasing demand for infrastructure to meet the future growth requirements of the country, waste generation is expected to increase with 'business as usual manner'.

The focus of the development process therefore needs to be such that waste generation is delinked from economic growth. Countries like Japan and South Korea[55] have shown that it is possible to reduce waste generation and maximize resource recovery and recycling while still pursuing the economic growth trajectory. For this to happen in India, the country will have to pursue the principles of circular economy and improve resource use efficiency to the levels of developed economies. Apart from improving resource efficiency, it is also important to adopt low carbon or zero carbon development strategies to address the current climate change issues. Waste sector has important role to play here as resource recovery from waste including energy recovery will lessen the need to mine and refine virgin resources thus will result into net reduction in carbon emission. Fortunately, India has already embraced the policy on circular economy[56] and come out with circular economy action plan for eight industrial sector including electronics (includes e-waste as well) and construction (includes construction and demolition waste as well).

The Hon'ble Prime Minister has also launched global Mission LIFE (Life Style for Environment) which also emphasizes the need for individuals to minimize wasteful consumption, reduce wastage and recover and recycle waste.

In addition, key recommendations for six waste streams discussed in the report are captured below:

6.1 Municipal Solid Waste

Though large numbers of households now segregate waste as a result of sustained efforts under Swachh Bharat Mission Phase-I and II however the processing of organic waste and value recycling is still the gap area. Key recommendations include:

[55] https://www.downtoearth.org.in/news/waste/ten-zero-waste-cities-how-seoul-came-to-be-among-the-best-in-recycling-68585
[56] https://pib.gov.in/PressReleasePage.aspx?PRID=1705772

- Improving collection in user charges from waste generators to fund the waste management services
- Deploy IT based tracking of waste management services to bring in accountability and transparency in the waste management process
- Setting up material recovery facility (MRF) across the cities to further sort the dry waste for value recycling. Engaging information waste collectors in door step collection of waste and also as work force at MRFs
- Wet waste processing close to the source of waste generation to reduce to cost of transportation and need for landfill space
- Setting of RDF processing facilities to process combustible, non-recyclable waste to produce high quality of waste derived fuel which can be used by Cement Kilns or other industries using coal
- Remediation of legacy waste dumpsites and develop integrated waste management facilities
- Awareness building on separate collection of sanitary pads and other household hazardous wastes and strategy for disposal

6.2 Plastic Waste

Plastic packaging waste which is around 45 per cent of total plastic waste generated is a matter of concern as much of it is single use and low value and hence often not collected by waste pickers. For effective plastic waste collection, the PWM Rules of 2016 provide provision of EPR which mandates manufacturers or brand owners using the plastic packaging to ensure collection of post-consumer plastic waste. Further, to tackle the menace of plastic waste litter, Government has banned many single use plastic (SUP) items with effect from July 2022. Specific recommendations for addressing plastic waste issues include:

- Reduction strategies for unnecessary packaging to reduce plastic waste. Adoption of Design for Environment (DfE) and Design for Recycling (DfR) principles for producing sustainable products.
- Promoting repair culture to enhance life of products.
- Joint partnership between ULBs and manufacturers and brand owners for effective implementation of EPR to maximise plastic waste collection and recycling.

6.3 Industrial Hazardous Waste

Much of industrial hazardous waste is regulated in the country as it is generated by the industrial units authorized by respective State Pollution Control Boards. The key issues are effective utilization, mining over burden, addressing legacy contaminated sites and challenges to recycle waste of smelting operations. The key recommendations to handle hazardous waste include:

- Adopting zero waste to landfill approach in the industries generating hazardous waste by adopting green chemistry manufacturing approach or researching on novel ways to recycle hazardous waste.
- Implementation of action plan for clean-up of legacy contaminated sites. A national fund needs to be created to support such efforts.

6.4 Biomedical Waste

Though the biomedical waste is generated in lesser quantities compared to other waste streams, however it is utmost important to keep biomedical waste segregated and timely transportation and its processing due to its infectious nature. The key recommendations for biomedical waste management include:

- Ensuring that no biomedical waste is littered or disposed at municipal waste disposal facility.
- The recyclable component of biomedical waste is properly cut and disinfected to avoid its reuse.

6.5 E-waste

This is one of the fastest growing waste streams due to intense application of digital resources and many a times short life for many electronic gadgets. The key recommendations for properly managing e-waste include:

- Like plastic waste, the partnership of manufactures or retailers of e-waste products with ULBs for their effective collection under the mandate of EPR.
- Research on adopting DfE and DfR for designing the electronic products to facility recovery and recycling while ensuring reduction in hazardous waste.
- Implementation of repairing capabilities to enhance the life of product.
- Transition of informal e-waste recyclers to formal recycling system by training and capacity building to address not only the pollution from informal e-waste recycling but also enhance recovery of semi-precious and precious metal recovery.

6.6 Construction and Demolition Waste

Construction and demolition (C&D) waste is also one of the fast growing waste streams owing to huge infrastructure development and its repair and maintenance. Presently only few cities have C&D waste recycling facility and most of C&D waste either remains dumped in low lying areas, vacant plots, on the road sides or reached the MSW disposal site and thus occupying valuable space though most of can be recycled. The key recommendations for addressing the issues of effective C&D waste management include:

- Setting up adequate numbers of C&D waste recycling facilities across the country
- Accelerate use of recycled C&D waste into construction activities and create market for recycled C&D waste products
- Regulate C&D waste generators strictly to avoid illegal C&D waste dumping

6.7 Summing up and way forward

Considering the seriousness and probability of health and environmental risks, and mapped out relevant actors and legislation, the next step is to identify governance problems related to waste management. The lack waste policies and legal clarities, coordination gap between relevant authorities and poor monitoring and control systems have aggravated the consequences of improper waste management. Apart from this, technological advancement is an important factor that can drive effective waste management in India.

Keeping in view of importance of MSW and considering the environmental impacts, timely audits should be planned to determine the economy, efficiency and effectiveness of the waste management strategies. The audit can also help in validating the controls in place and also to assess the sufficiency and effectiveness of the waste generated or collected in complying with various laws in force. In upcoming years, the audits should be planned to include all stake holders from central level as well as at state level because in federal structure, some of the flagship schemes are cross cutting in nature and implemented by several ministries and departments who otherwise work on their separate mandates but ultimately working for the same target/goal.

Bibliography

1. Annual report of CPCB related to waste generation, segregation and processing retrieved from: https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf
2. 74th Constitutional amendment: (https://mohua.gov.in/upload/uploadfiles/files/74th_CAA13.pdf)
3. Definitions of Waste: : (https://en.wikipedia.org/wiki/Waste#:~:text=Wastepercent20perpercent20cent20isperce nt20perpercent20cent20anypercent20perpercent20cent20substancepercent20perpercent2 0cent20which,wastepercent20perpercent20cent20product'spercent20perpercent20cent20 valuepercent20perpercent20cent20abovepercent20perpercent20cent20zero)
4. Solid waste manual 2016 issued by MoHUA: https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf
5. Components of waste: https://www.aboutcivil.org/physical-characteristics-of-solid-waste
6. Moisture Content of Solid Waste : http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2595
7. Size of Waste Constituents:http://ecoursesonline.iasri.res.in/mod/page/view.php?id=2595
8. Calorific Value: https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf
9. Definition of municipal solid waste: https://vikaspedia.in/energy/environment/waste-management/municipal-solid-waste-management
10. Definition of domestic waste: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/domestic-waste
11. Definition of commercial waste: https://envirocareusa.com/blog/356-differences-between-commercial-and-domestic-waste
12. Definition of Industrial waste: https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
13. Definition of Hazardous waste: https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
14. Definition of Agriculture waste: https://www.yourarticlelibrary.com/solid-waste/6-main-types-of-solid-waste-management/30162
15. Definition of Bio medical waste: https://www.environmental-auditing.org/media/5375/wgea-waste-managemen_e.pdf
16. Definition of Plastic waste: http://jkspcb.nic.in/Content/Plastic.aspx?id=230

17. Definition of E-waste: https://www.environmental-auditing.org/media/5375/wgea-waste-managemen_e.pdf

18. Importance of Reduce: https://www.ques10.com/p/52549/what-are-3r-explain/

19. Municipal Solid Waste Manual-II issued by MoHUA retrieved from: https://mohua.gov.in/upload/uploadfiles/files/Part2.pdf

20. Manual on Municipal Solid Waste Management(First edition) issued by by MoHUA retrieved from: http://cpheeo.gov.in/cms/manual-on-solid-waste-management.php

21. Definition of composting : https://mohua.gov.in/upload/uploadfiles/files/Part2.pdf

22. In the State of Rajasthan, Awas Vikas & Infrastructure: https://indiagarbagecase.in/wp-content/uploads/2019/11/RAJASTHAN-2017.02.28.pdf

23. National Environment Policy, 2006 retrieved from: https://ibkp.dbtindia.gov.in/DBT_Content_Test/CMS/Guidelines/20190411103521431_Nationalpercent20Environmentpercent20Policy,percent202006.pdf

24. SWM state subject: http://cpheeo.gov.in/upload/uploadfiles/files/Advisorypercent20onpercent20Improvingpercent20Municipalpercent20Solidpercent20Wastepercent20Managementpercent20Services.pdf

25. Report No. 4 of the year 2018 of Government of Karnataka on Performance audit of Solid Waste Management in Urban Local Bodies retrieved from: https://cag.gov.in/webroot/uploads/download_audit_report/2018/Report_No_4_of_2018_Performance_Audit_of_Solid_Waste_Management_in_Urban_Local_Bodies_Government_of_Karnataka.pdf

26. Overview of CPCB: https://cpcb.nic.in/technical-guuidelines/

27. Overview of Swachh Bharat Mission: https://jalshaktiddws.gov.in/sites/default/files/Swachhpercent20Bharatpercent20logopercent201.pdf

28. Lok Sabha Unstarred Question no. 1882 dated-28/07/2022 retrieved from : https://loksabha.nic.in/

29. Report No. PA 14 of 2008 for the Period ended March 2007 - Management of Waste in India: https://cag.gov.in/cag_old/content/report-no-pa-14-2008-period-ended-march-2007-management-waste-india

30. Report No.2 of 2019 - Government of Goa : https://cag.gov.in/uploads/download_audit_report/2019/Report_No_2_of_2019_Government_of_Goa.pdf

31. Report No.2 of 2018 - Local Bodies Government of Rajasthan: https://cag.gov.in/uploads/download_audit_report/2018/Report_No_2_of_2018_-_Local_Bodies_Government_of_Rajasthan.pdf

32. Report no. 2 of 2019 - Social, Economic (other than PSUs), Economic (PSUs), Revenue and General Sectors Government of Manipur: https://cag.gov.in/uploads/download_audit_report/2019/Report_no_2_of_2019_Social_Economic_other_than_PSUs_Economic_PSUs_Revenue_and_General_Government_of_Manipur.pdf

33. Report no 2 of the year 2021 of Government of Himachal Pradesh for the year ended 31st March, 2019: https://cag.gov.in/en/audit-report/download/114173

34. Overview of Anaerobic Digestion: https://www.epa.gov/agstar/how-does-anaerobic-digestion-work#:~:text=Anaerobic per cent20digestion per cent20is per cent20a per cent20process,in per cent20the per cent20absence per cent20of per cent20oxygen

35. Overview of Incineration: https://en.wikipedia.org/wiki/Refuse-derived_fuel

36. Overview of Pyrolysis: https://www.bioenergyconsult.com/pyrolysis-of-municipal-waste/

37. Overview of Gasification: https://www.climatecolab.org/contests/2016/waste-management/c/proposal/1329507

38. Overview of Plasma Gasification: https://blog.mywastesolution.com/advantages-and-disadvantages-of-plasma-pyrolysis/

39. Overview of Autoclaving: https://en.wikipedia.org/wiki/Waste_autoclave#:~:text=A per cent20waste per cent20autoclave per cent20is per cent20a,temperatures per cent20around per cent20160 per cent20 per centC2 per centB0C

40. Overview of Microwaving: https://www.malsparo.com/treat2.htm

41. Sustainable materials management (SMM): https://www.epa.gov/smm/sustainable-materials-management-basics

42. Best practices in municipal solid waste management issued by NITI Aayog retrieved from: https://www.niti.gov.in/sites/default/files/2021-12/Waste-Wise-Cities.pdf

43. Biogas initiative by Pune: https://www.pmc.gov.in/en/biogas-initiative

44. Swachta Sarvekshan by MoHUA: https://www.mygov.in/mygov-survey/swachh-survekshan-2022/

45. Circular economy in Indore: https://imcindore.mp.gov.in/?page_id=2452

46. Compendium on works of interns at iCED: https://fliphtml5.com/dnddh/bmlr/

Annexure - A
(Reference para no. 3.4)
List of Audit Reports on Waste Management (2018 to 2022)

Sl. No.	Year	Title of the Report	Type of report	Link of the CAG Reports (Period 2018-2022)	Union/ State	Issue
1	2022	Report No.16 of 2022 - Performance Audit on Waste Management in Indian Railways, Union Government (Railways)	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2022/Reportpercent20No.percent2016percent20ofpercent202022_PApercent20onpercent20Railwaypercent202019-20_English_(5-7-2022)-062f0ee4400ba47.16865688.pdf	Union	Waste Management in Indian Railways
2	2022	Report No. 2 of 2022 - Compliance audit of the Departments under Social, Economic, General and Revenue Sectors, Government of Arunachal Pradesh	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2022/Auditpercent20Reportpercent202019-20-063295dfb834be1.69469104.pdf	State - Arunachal Pradesh	Implementation of the Swachh Bharat Mission in Arunachal Pradesh
3	2022	Report No. 2 of the year 2022 - Audit of Local Bodies in Rajasthan for the year ended 31 March 2020, Government of Rajasthan.	Compliance Audit	https://cag.gov.in/uploads/download_audit_report/2022/ARpercent20REPORTpercent20LBpercent20ENGLISHpercent20Combined-0632c0c6ba362e0.34289980.pdf	State - Rajasthan	Waste Management in Urban local Bodies
4	2021	Report No. 2 of the year 2021 Government of Himachal Pradesh	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2021/Reportpercent20No.percent202percent20ofpercent202021_N-PSUspercent202018-19_English-061164670ed24b6.45465549.pdf	State- Himachal Pradesh	Solid Waste Management in Urban Areas

4	2020	Report No. 5 of 2020- General and Social Sector Government of Gujarat for the year ended March 2019	Compliance Audit	https://cag.gov.in/uploads/download_audit_report/2020/AGpercent20GSSpercent20Engpercent2018-19-FULL_REPORT-05f8d5e095f1e93.70851670.pdf	State - Gujarat	Management of Municipal Solid Waste in Select Urban Local Bodies
5	2020	Report No. 4 of 2020- General and Social Sector Government of Tamil Nadu for the year ended March 2019	Performance Audit	https://cag.gov.in/webroot/uploads/download_audit_report/2019/AR-GSSA-ENGLISH-2018-19-CHAPTER-II-060d9b8b09ef1d5.89120524.pdf	State - Tamil Nadu	Sewage Management in Chennai Metropolitan Area
6	2020	Report 5 of the year 2020 - Public Sector Undertakings for the year ended March 2019	Compliance Audit	https://cag.gov.in/uploads/download_audit_report/2020/ARpercent202018-19percent20PSUpercent20Karnatakapercent20English-0601bbcf9854907.02066113.pdf	State - Karnataka	Waste management at bus stations
7	2019	Report no. 2 of 2019 - Social, Economic (other than PSUs), Economic (PSUs), Revenue and General Sectors Government of Manipur	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2019/Report_no_2_of_2019_Social_Economic_other_than_PSUs_Economic_PSUs_Revenue_and_General_Government_of_Manipur.pdf	State - Manipur	Solid Waste Management
8	2019	Report No.2 of 2019 - Government of Goa	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2019/Report_No_2_of_2019_Government_of_Goa.pdf	State - Goa	Management of Solid Waste in Goa
9	2019	Report No. 02 of the year 2019 Hospital Management in Uttar Pradesh for the year ended 31 March 2018	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2019/Report_No_2_of_2019_Hospital_Management_in_Uttar_Pradesh_Government_of_Uttar_Pradesh.pdf	State - Uttar Pradesh	Hospital Waste Management in Uttar Pradesh

10	2019	Report no. 4 of 2019 - Social, General and Economic (Non-PSUs) Sectors Government of Assam	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2019/Report_no_4_of_2019_Social_General_and_Economic_(Non-PSUs)_Sectors_Government_of_Assam.pdf	State - Assam	Delivery of Core Basic Services by Urban Local Bodies
11	2019	Report No.16 of 2018 - Performance Audit of Working of Inland Container Depots (ICDs) and Container Freight Stations (CFSs) Department of Revenue Indirect taxes, Customs	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2018/Report_No_16_of_2018_Performance_Audit_of_Working_of_Inland_Container_Depots_(ICDs)_and_Container_Freight_Stations_(CFSs)_Department_of_Revenue_Indirect_taxes_Customs.pdf	Union	Hazardous waste
12	2018	Report no. 4 of 2018 - Performance Audit of Solid Waste Management in ULB Government of Karnataka	Performance Audit	https://cag.gov.in/cag_old/sites/default/files/audit_report_files/Report_No_4_of_2018_Performance_Audit_of_Solid_Waste_Management_in_Urban_Local_Bodies_Government_of_Karnataka.pdf	State - Karnataka	Solid Waste Management in Urban Local Bodies
13	2018	Report No.2 of 2018 - Local Bodies Government of Rajasthan	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2018/Report_No_2_of_2018_-_Local_Bodies_Government_of_Rajasthan.pdf	State - Rajasthan	Waste Management of Urban Local Bodies

14	2018	Report No.5 of 2018 - Performance Audit of Pollution by Industries in West Bengal, Government of West Bengal	Performance Audit	https://cag.gov.in/uploads/download_audit_report/2018/Report_No_5_of_2018_Performance_Audit_of_Pollution_by_Industries_in_West_Bengal_Government_of_West_Bengal.pdf	State - West Bengal	Pollution by Industries
15	2018	Report No.1 of 2018 - Government of Uttarakhand on Solid Waste Management in Nagar Nigams of Dehradun and Haridwar	Compliance Audit	https://cag.gov.in/webroot/uploads/download_audit_report/2018/Report_No_1_of_2018_-_Government_of_Uttarakhand.pdf	State - Uttarakhand	Solid Waste Management in Nagar Nigams of Dehradun and Haridwar
16	2018	Report No. 1 of 2018- Local Bodies Report of Odisha on Implementation of Swachh Bharat Mission	Compliance Audit	https://cag.gov.in/webroot/uploads/download_audit_report/2018/English_Reportpercent20No1percent20ofpercent202018(LBs).pdf	State - Odisha	Implementation of Swachh Bharat Mission

Annexure B
(Reference para no. 2.4.3)
Modern technologies for treatment of Municipal Solid Waste

1. **Anaerobic Digestion**[57]

Anaerobic digestion is a process in which bacteria break down organic matter such as animal manure, waste-water bio-solids and food wastes in the absence of oxygen. Anaerobic digestion for biogas production takes place in a sealed vessel called a reactor. Complex microbial communities are found in these reactors, which break down waste to produce biogas and digest ate the solid and liquid by-products of the AD process, which are discharged from the digester.

Anaerobic digestion produces two valuable outputs: - Biogas and Digestate

Biogas - Methane (CH4), the main component of natural gas, constitutes between 50 per cent and 75 per cent of biogas along with carbon dioxide (CO2), hydrogen sulphide (H2S), water vapor, and trace quantities of other gases. Like natural gas, biogas may be utilised for a variety of purposes, including the production of electricity, the operation of cooling systems, and the provision of heat.

Digestate - Digestate is the waste product of the digestive process. It is made up of both liquid and solid components. With the proper processing, digestate's solid and liquid components can be used in a variety of advantageous ways, including as animal bedding (solids), nutrient-rich fertilizer (liquids and solids), a building block for bio-based products (such as bioplastics), organically rich compost (solids), and/or just as a soil amendment (solids).

2. **Refuse Derived Fuel**[58]

Refuse-derived fuel (RDF) is a fuel produced from various types of waste such as MSW, industrial waste or commercial waste. RDF is mostly composed of flammable waste components such as non-recyclable plastics (except PVC), paper cardboard, labels, and other corrugated materials. These fractions are separated through various processing steps such as screening, air classification, ballistic separation, separation of ferrous and non-ferrous materials, glass, stones, and other foreign materials, and shredding into a uniform grain size, or palletisation to produce a homogeneous material that can be used as a substitute for fossil fuels in cement plants, lime plants, coal-fired power plants, or as a reduction agent in steel furnaces.

3. **Incineration**[59]: - In this process waste material is converted into ash, flue gas, and heat. The mass of waste is reduced by 95 to 96 per cent when processed through incineration. It is a good choice for places that have a shortage of land. It is operable in any weather condition.

[57] https://www.epa.gov/agstar/how-does-anaerobic-digestion-work#:~:text=Anaerobic per cent20digestion per cent20is per cent20a per cent20process,in per cent20the per cent20absence per cent20of per cent20oxygen.
[58] https://en.wikipedia.org/wiki/Refuse-derived_fuel
[59] https://en.wikipedia.org/wiki/Refuse-derived_fuel

Incineration is essential for making waste management simpler and more efficient. Incineration has the potential to burn up to 90 per cent of total waste generated, and occasionally even more. Landfills on the other hand, only allow for organic decomposition while non-organic waste continues to accumulate.

4. **Pyrolysis[60]:** Pyrolysis is a fast-growing biomass thermal conversion technique that has gained widespread interest due to its high efficiency and environmentally friendly performance caracteristics. The pyrolysis technique allows for the conversion of municipal solid waste, agricultural residues, scrap tyres, non-recyclable plastics, and other pollutants into clean energy. It provides an appealing method of transforming urban garbage into goods that may be used to generate heat, power, and chemicals.

When carbon-rich organic material is heated in a non-reactive environment, the pyrolysis process involves both simultaneously and sequential reactions. Pyrolysis is simply the thermal breakdown of organic molecules in the absence of oxygen. In the absence of air/oxygen, the thermal breakdown of organic components in the waste stream begins around 350°C-550°C and progresses to 700°C-800°C. Municipal waste pyrolysis begins with mechanical preparation and separation of glass, metals, and inert materials before processing the remaining garbage in a pyrolysis reactor. Rotary kilns, rotary hearth furnaces, and fluidized bed furnaces are the most often utilized pyrolysis reactors. The main products obtained from the pyrolysis of municipal wastes are a high calorific value gas (synthesis gas or syngas), a biofuel (bio oil or pyrolysis oil) and a solid residue.

5. **Gasification[61]**: Gasification converts MSW to usable synthesis gas or syngas. Gasification is a novel technique that converts carbon-based materials like MSW or biomass into different types of energy without burning them. Instead, gasification uses a chemical reaction to turn solid and liquid waste products into gas. This reaction combines carbon-based materials (known as feedstock) with small amounts of air or oxygen (but not enough to burn the materials), resulting in simple molecules, primarily a combination of carbon monoxide and hydrogen.

6. **Plasma Gasification[62]:** Pyrolysis is the thermal breakdown of organic compounds in the absence of oxygen at elevated temperatures. It securely destroys plastic, medical, and other hazardous waste. Plasma pyrolysis which emerged in the early 1990s, is a high-temperature thermal process that converts organic materials into gases and inaccessible solid residue. It is carried out in an oxygen-depleted environment. Plasma torches powered by electric arcs are used to ionize the gas, which catalysis the conversion of organic materials to syngas and slug.

[60] https://www.bioenergyconsult.com/pyrolysis-of-municipal-waste/
[61] https://www.climatecolab.org/contests/2016/waste-management/c/proposal/1329507
[62] https://blog.mywastesolution.com/advantages-and-disadvantages-of-plasma-pyrolysis/

7. **Autoclaving**[63]**:** A waste autoclave is a type of solid waste treatment that processes waste using the heat, steam, and pressure of an industrial autoclave. Waste autoclaves could treat waste in batches or continuously. Saturated steam is pumped into the autoclave at temperatures of approximately 160°C in batch processes. The steam pressure in the vessel is kept at 6 bar (gauge) for up to 45 minutes to allow the process to completely 'cook' the waste. To achieve full sterilisation of pathogenic waste, some autoclaves also known as waste converters can work in the atmospheric pressure range. Variable pressure control, which cycles between ambient and negative pressure within the sterilising vessel, achieves super-heating conditions and steam generation. In "batch system" autoclave procedures, the "cooking" process softens and flattens plastics, disintegrates paper and other fibrous materials into a fibrous mass, cleans bottles and metal items and removes labels etc.

8. **Microwaving**[64]**:** Waste-water sludge is treated with microwave radiation, and medical waste is heated with microwave radiation. On-site installations or mobile treatment vehicles can both contain microwave treatment units. The procedure frequently includes front-end shredding of the trash, both to boost the efficacy of the microwave treatment and to lower the volume of the final waste for disposal. If the garbage is dry, water is added before it is placed inside the microwave chamber as moist waste. The microwave machine transfers energy as microwaves and that energy transforms into heat inside the wet waste, whereas an autoclave, like a traditional cooking oven, offers heat from outside the waste.

Only water in the garbage can be disinfected using a microwave because the radiation immediately affects the water and not the waste's solid components. Because of this, humidifiers are frequently included in treatment units. Although it won't chemically alter hazardous materials the way incineration can, microwave treatment of medical waste is less expensive than incineration.

[63] https://en.wikipedia.org/wiki/Waste_autoclave#:~:text=A per cent20waste per cent20autoclave per cent20is per cent20a,temperatures per cent20around per cent20160 per cent20 per centC2 per centB0C

[64] https://www.malsparo.com/treat2.htm