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Waste Management a Sustainable System with Waste Reduction Techniques

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ABSTRACT:
As industries expand globally and increase manufacturing capacities, they produce new products and generate unwanted waste materials. In recent years, non-compliance in handling, storing, and disposing of these wastes has led to penalties by the National Green Tribunal in India. These wastes not only pose significant environmental issues but also represent material and fuel losses, as well as increased carbon footprints. Traditionally, pollution control has focused on "end-of-the-pipe" treatments, which do not effectively manage waste and result in disposal challenges.
Stringent regulations, rising waste disposal costs, and operational expenses have prompted manufacturers and government leaders to critically monitor end-of-the-pipe control measures. Emphasizing waste reduction techniques at the source to eliminate waste generation has become a key sustainable objective for many manufacturing industries. These units are now prioritizing broader sustainability development by implementing comprehensive environmental management objectives. Effective waste management not only provides economic benefits to manufacturing plants but also enhances environmental conditions

Keywords: end of the pipe; National Green Tribunal; Sustainability Development; non-compliance

Introduction:

Waste management is a burning issue that affects environmental issues, hygiene issues, and disposal costs issues. This improper waste disposal leads to air/water/soil pollution, hygiene, and disposal losses. Hence, it is essential to have better practices and techniques. This research paper provides a comprehensive review of types of waste, characteristics of waste, practices, and techniques, taking through the current trends, challenges, and future scope dealing with the functional elements involved in waste management.

Types of Waste:

Based on its origin, composition, and impact on the environment can be classified below in Figure 1

1. Municipal solid waste
2. Hazardous waste
3. Biomedical waste
4. e-waste
5. Agricultural waste
6. Industrial waste
7. Construction debris waste
8. Radioactive waste

Municipal Solid Waste (MSW): Municipal solid waste means daily waste generated from households, commercial complexes, and institutions like food waste, paper waste, plastic waste, broken glass, metal scrap, etc. MSW is collected by local authorities and disposed of through various methods such as landfilling, incineration, composting, or recycling.

Hazardous Waste: Hazardous waste means waste that has an impact on health and the environment due to its characteristic properties. They are toxic, flammable, corrosive, reactive, or infectious like solvents, pesticides, batteries, fluorescent bulbs, and medical wastes (e.g., sharps).

Biomedical Waste: Biomedical waste means waste generated from healthcare activities like discarded needles, syringes, bandages, and culture waste.

e-waste: e-waste means discarded electronic devices such as computers, televisions, mobile phones, printers, and other electronic equipment containing hazardous materials like lead, mercury, cadmium

Agricultural Waste: Agricultural waste means byproducts from agricultural activities like crop residues, manure, and package waste from farming operations.

Industrial Waste: Industrial waste means waste from Process, manufacturing, and power plants like chemicals, petroleum refining, mining, textiles, food processing, and construction and debris contamination.

Construction and Demolition Waste: Construction and demolition means waste from construction, renovation, or demolition activities. Like concrete, bricks, wood, metals, plastics, glass, insulation materials, and packaging.

Radioactive Waste: Radioactive waste means waste that has contamination of radioactive substances like nuclear power plants, medical facilities using radioactive isotopes for diagnosis or treatment, research institutions, and industrial processes involving radioactive materials.

Characteristics of Waste:

1. Physical:

Waste varies in physical characteristics based on its composition and source.

a. Size and Volume
b. Density
c. State
d. Moisture Content

2. Chemical:

Waste varies in chemical characteristics based on its composition and source. They determine potential environmental and health risks associated with waste.

a. pH
b. Toxicity
c. Flammability
d. Reactivity
e. Persistence

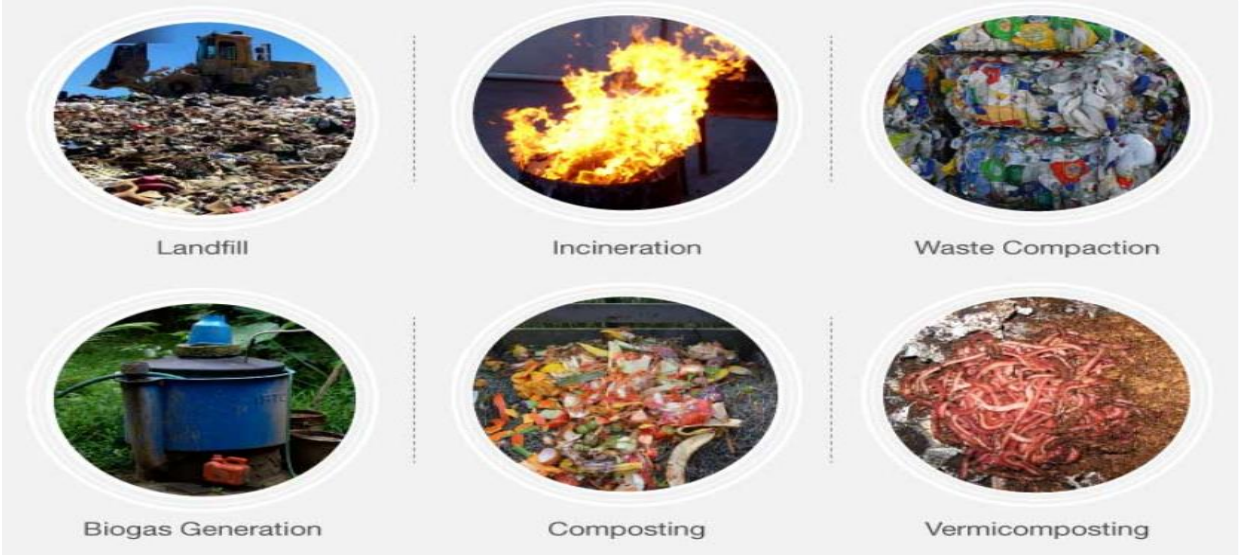
3. Biological:

Biological characteristics of waste primarily pertain to organic waste materials.

a. Decomposability
b. Putrescibility
c. Pathogenicity

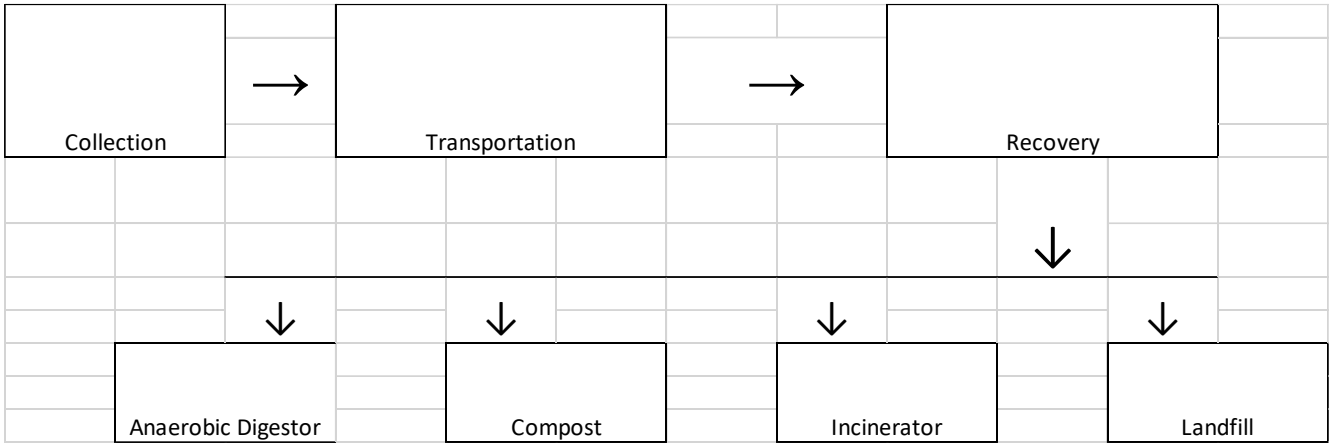
Methods of Waste Management:

Figure 2



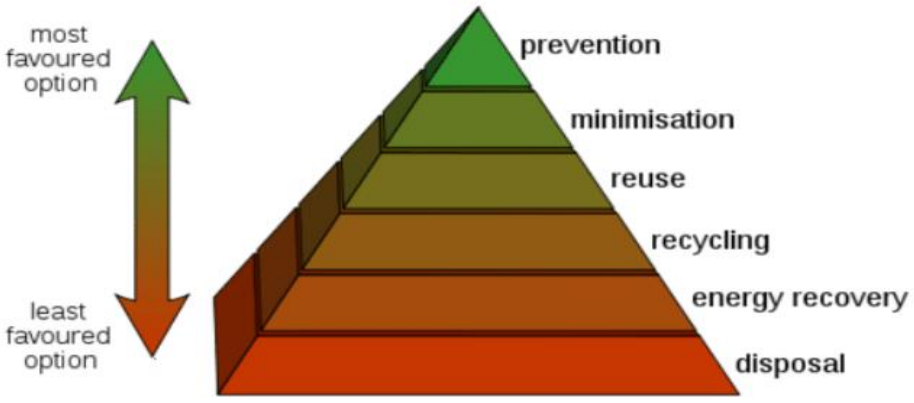
Steps in Waste Management:

Figure 3



Hierarchy of waste management:

Figure 4



Waste reduction techniques are vital for cost effectiveness and require simple technology with low expenditure and can be applied to all type of manufacturing process.

They are categorized into

1. Inventory management,
2. Process modification,
3. Waste volume reduction and
4. Waste recovery.

Inventory management:

Optimizing of raw materials, intermediates, finished products, and waste is a critical waste reduction technique. In many instances, raw materials/intermediates/finished products if not optimized they become "off-spec,", process/packing spillages will be collected as an additional waste increasing disposal costs as well as lost material cost. Inventory control just by strategic procurement procedure will reduce major waste sources from non-strategic inventory control: excess storage, expired, and non-moving raw materials. Raw material inventory based on actual /specific consumption is a key method. Awareness on disposal costs and compliance issues to purchase personnel helps in better inventory management by strategic planning in procurement with more shelf life. Periodic stocks tracking and alerts of expiry in advance helps to utilize material in advance to avoid off specs. To develop review and approval procedures in inventory control to procure raw material with less hazardous and also to develop cleaner raw materials without any hazardous content. To develop JIT (Just in Time) concept in which material received from suppliers when needed. This helps to reduce waste generation while storage and handling, Ex: Toyota

Process modification:

Efficiency improvement in process will reduce waste generation at source, hence process modification methods to be adopted like

1. Implement standard operating procedures, preventive maintenance and optimize process controls to improve efficiency
2. Implement Green Chemistry
3. Upgrade / Modify Equipment to improve efficiency

Implement standard operating procedures, preventive maintenance and optimize process controls to improve efficiency:

Implementation of standard procedures to process as per the norms avoiding excess utilization and wastage. Maintenance of equipment's as per preventive maintenance required to be scheduled. These methods though not new, not complex, it is inexpensive and Capex not required with below benefits

- Fresh water consumption decreases by 5% to 10%
- Reduces unwanted contamination reducing organic load in waste water
- Avoids energy loss in waste water treatment by MEE & RO
- Eliminates landfill disposal

Another area which is ignored and generally overlooked is material handling. Standard material handling procedures ensures no leakages/spillages while storage and shifting.

Another area which needs utmost focus is maintenance, as 25% additional waste generated during process is due to poor maintenance. Preventive maintenance avoids equipment breakdowns and minimize

downtimes. This is very effective to arrest leaks and failures in time before benefits of waste management program are washed out with down time losses and batch failures. A good maintenance procedure consists of maintenance cost analysis tracking, preventive maintenance schedule, condition monitoring and predictive maintenance.

As standard procedures are documented they should be reviewed periodically in every one year and impart employee training program involving all levels of employees with refresh trainings based on training need identification.

Important points of waste reduction by implementing Operational procedures

1. Reduce material loss by leakages, spillages
2. production planning to reduce cleaning of equipment
3. Preventive maintenance to reduce equipment failure
4. Upgrade dry cleaning methods to avoid generation of waste
5. Waste segregation and collection to increase recovery and reuse.
6. Optimization of process parameters to reduce generation of by-products
7. Training need identification on waste management and imparting trainings
8. Evaluate and eliminate unwanted process steps.

Implement Green Chemistry:

Green chemistry focuses on the design and development of chemical products and processes that minimize the use and generation of hazardous substances. It promotes the principles of sustainability, like waste reduction, specific energy consumption, and environmental foot prints by product life cycle.

Product reformulation by design of safer raw materials with less hazardous material is quite effective technique. Ex: Water based solvents usage instead of organic solvents in Inks, paints. Cleaning solvents replaced with water-based products in diesel engines reducing its coolant, cleaning costs, labor costs. But there could be a negative impact of increasing in waste water streams quantity. Hence impact of discharge, sludge quantity to be evaluated before any process modification.

Industrial examples of green chemistry:

1. Replacing non renewable with renewable resources, fossil fuels with solar, wind, agriculture waste etc.
2. Replace cyanide cadmium plating bath with a non-cyanide bath in aerospace
3. Usage of UV light instead of biocides in cooling towers
4. Cleaning solvents replaced with water-based products in diesel engine manufacturing.
5. Catalysis, which enables chemical reactions to occur under milder conditions, reducing energy consumption and waste generation.
6. Biodegradable polymers in packaging which can breakdown due to exposure to sunlight, temperature, microbes

Upgrade / Modify Equipment to improve efficiency:

Redesign of equipment, addition or removal of components can improve efficiency avoiding wastages. This upgradation not only reduces waste but also minimizes off specs avoiding breakdowns.

Industrial examples of Equipment modification/upgradation

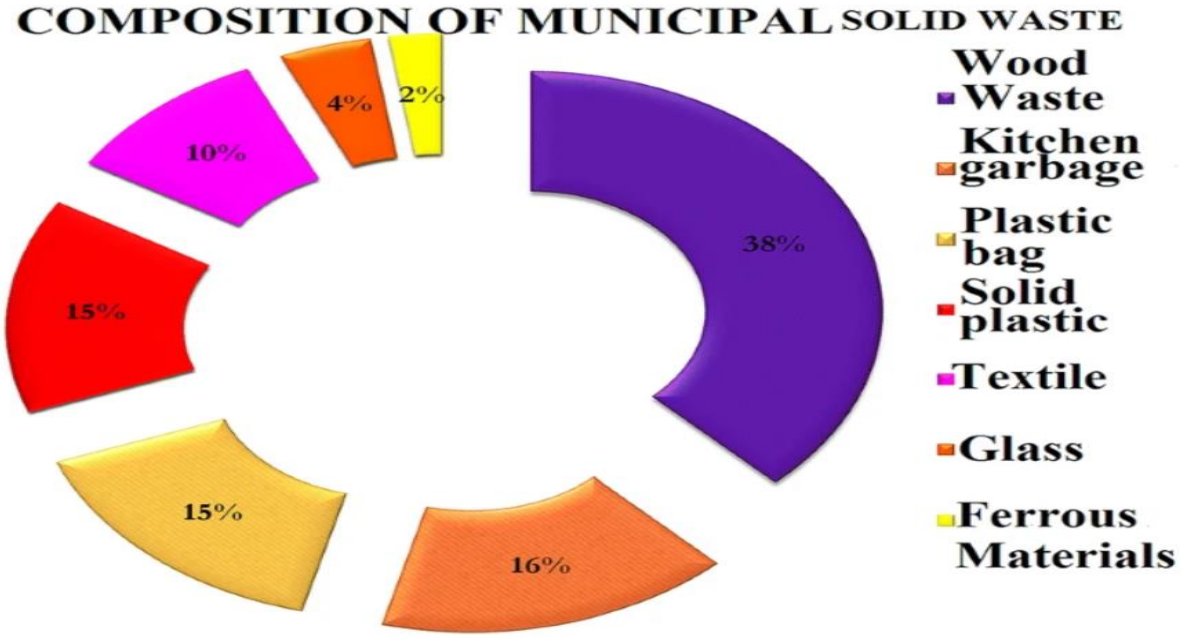
1. Installing seal less pumps to eliminate leakage.
2. Installing drip pans under equipment to collect leakages for reuse.
3. Install overflow control devices, splash guards, dykes to control spillages
4. Use welded pipe joints replacing flange joints to control leakages.

Waste Volume reduction:

Waste volumes can be reduced by segregation at source by separating toxic, hazardous and recoverable from waste streams. These consists of waste segregation at source to concentration of waste.

Waste segregation is a simple and economical technique in which handled hazardous and non-hazardous separately waste volumes and handling costs reduces.

Figure 5



Industrial Examples:

1. In Metal finishing units waste streams segregation helps in recovery of valuable metals from sludge.
2. Spent solvents or waste oil are kept segregated from other liquid waste then can be recycled to authorized recyclers.
3. If toxic stream separated from non-toxic stream, then volume of waste water for treatment can be reduced.
4. Collection of wash water, solvents used in cleaning equipment are reused in production process like toluene used in roller cleanup is segregated separately as per color and used later in thinning of same type of color

Concentration of waste is a technique in which mostly water is removed by some methods like vacuum filtration, Multiple effect evaporators, Drying, Ultra filtration and reverse osmosis.

Industrial examples:

1. Dewatering of sludge by filter press
2. Sludge drying in paddle dryer, tray dryer

Waste Recovery:

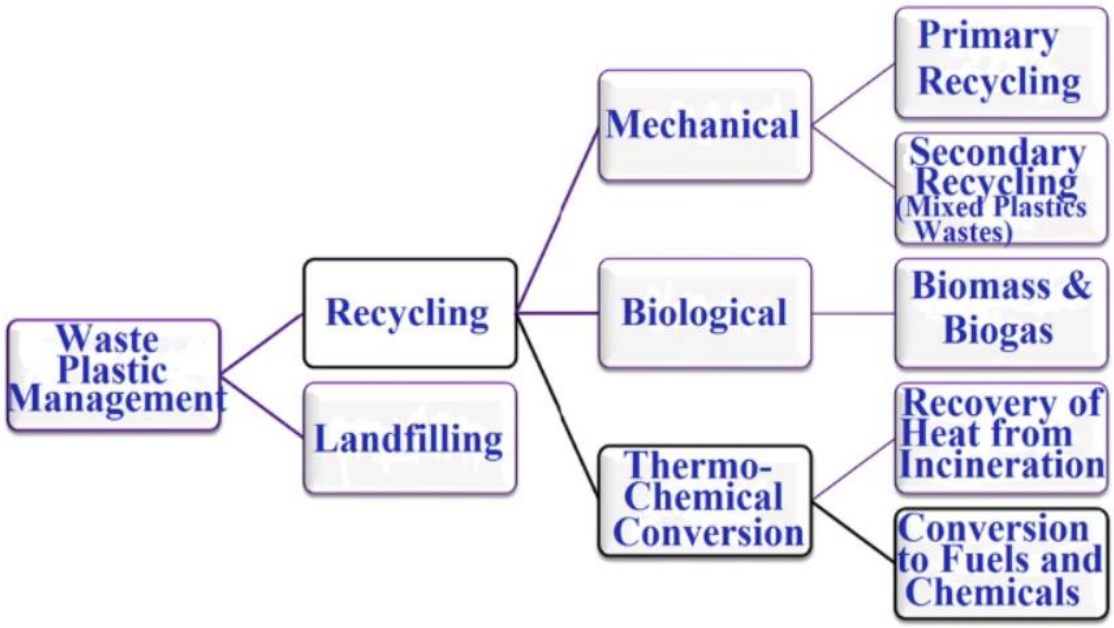
This is a cost-effective technique which eliminates disposal cost and generates revenue and its effectiveness depends on segregation of waste hence handling, collection, storage and recovery disposal plays vital role. The most suitable method is to recover at generation point as to segregate before any contamination and can be used in recycling. Some type of waste can be recovered by further treatment like filtration, distillation based on characteristics of waste stream. Some waste may not be recovered within plant if cannot be reused, not cost effective, no enough quantity generated, no recovery facility than it is sent to authorized recyclers for disposal /recovery

Industrial Examples:

1. Dust collector residue from pesticide plants
2. Spent solvents reuse in production or sent outside for authorized solvent recovery plants
3. Spent caustic in neutralization of acid waste stream
4. Spent acids in neutralization in waste water treatment
5. Spent oils sent to authorized recyclers
6. Spent acids disposed to authorized manufacturer can use as raw material in their production like HCL. phosphoric acid in Di calcium phosphate production.

Plastic Management:

Figure 6



Conclusion:

A waste reduction program is required with Management involvement, Data evaluation, Selection of best technology, Training and employee involvement, Monitoring, and analysis. In conclusion, waste management is a sustainable system when coupled with effective waste reduction techniques. By reducing waste at its source, promoting recycling and composting, utilizing waste-to-energy technologies, capturing landfill gas, implementing extended producer responsibility programs, practicing proper waste segregation, and raising public awareness, we can achieve a more sustainable approach to managing our waste.

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