Waste Management: A Paradigm Shift

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Abstract

According to the available data worldwide, more than 4 billion tons of waste is generated annually. This includes municipal, industrial, biomedical, hazardous, and e-waste. Generation of solid waste is directly proportional to the size of economy and population. Management of waste is a responsibility of every human being living on this earth. Recent report of World Health Organization (WHO) states that about 25% diseases in developing countries are due to improper waste management, leading to environmental pollution and ultimately to diseases. Waste can be classified into five broad categories including solid, industrial, plastic, e-waste, and biomedical wastes. Policy guidelines at national and international level were drafted and implemented for management of wastes, environmental protection, and sustainable development. Converting waste into energy like biogas, biofuels, and novozymes (an enzyme-based solution that converts low-grade oils and cooking oils into biodiesel) is a smart approach. Another important aspect is the recyclability of certain products like plastics. Identification of one plastic polymer from another is very challenging and hence their recyclability. All the developing countries need to ratchet up the recyclability procedures. Further, the attitude of people needs to change drastically for waste generation, e.g., people being charged for the amount of food wasted by them, enforcing them to change their attitude. In addition to that, process like *bioremediation* is playing a significant role in environmental cleanup and to

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remove toxins. It is the emerging green technology of environment conservation which explores the potential of microbes for degradation of xenobiotic compounds as well as eradication, transformation, and infringement of various other contaminants.

Keywords
Waste · Management · Biomedical · E-waste · Hazardous

14.1 Overview

Waste can be defined as substances or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law (UNEP 2003). Daily activities of all living creatures generates huge amount of wastes. Management of waste is one of the biggest problems that many developing and underdeveloped countries are facing. According to the available data worldwide, more than 4 billion tons of waste is generated annually. This includes municipal, industrial, biomedical, hazardous, and e-waste. Generation of solid waste is directly proportional to size of economy and population. Management of waste is a responsibility of every human being living on this earth. The cost of solid waste management is increasing annually, thus causing impact at global level. Cleaning and management of waste are less cost-effective as compared to reduction of generation at source. Management of waste is a herculean task that every country is facing. Management of waste is a wholesome process involving many steps including collection segregation, transportation, reprocessing, recycling, and disposal.

According to World Health Organization (WHO), about 25% diseases in developing countries are due to improper waste management, leading to environmental pollution and ultimately to diseases. One of the main cause of pollution is population and fast pace of urbanization particularly in developing countries, like India. India with 1.33 billion people is the second largest country in the world in terms of population after China. The population growth in India has been high with average rate of increase approx. 2% per annum. With a fast pace of urbanization, it is estimated that by next decade, more than 500 million people will start living in urban areas of the country. Not only big and small cities but small towns are facing problem of urban waste management, as piles of garbage left in open areas to rot. This problem is due to difference in requirement and availability of services (Mavropoulos et al. 2012).

Waste management in urban area is one of the critical issues as these cities are dumped with piles of garbage. The waste is lying in open land area to rot. This mismanagement or partial management of garbage is leading to soil, air, and water pollution and causing health impacts.

14.2 Waste Identification and Management

Proper waste identification is essential for its correct and effective treatment and management of it. Is it a solid waste, a liquid waste, hazardous waste, etc.? If the waste identified is hazardous, it has to be properly managed, or else it will cause a severe risk to the environment as well as human well-being. The Resource Conservation and Recovery Act (RCRA) has streamline a structure for proper management of hazardous wastes. All the waste generators must settle on the types of waste generated by them and must watch over the ultimate fate of those wastes. Additionally the generators must ensure and fully document that the waste generated by them is correctly identified, transported, and treated before recycling and disposal process. The waste generated is transported further to facilitate its treatment, disposal, or recycling process; since the transportation would be carried out on public roads, railways, and waterways, various guidelines come in action, for example, the US Department of Transportation Hazardous Materials Regulations and US Environmental Protection Agency (EPA). There are also proper guidelines for temporary storage and final treatment and disposal of hazardous wastes, failing which could lead to unmanageable results.

14.2.1 Identification of Waste Factors in Various Manufacturing Processes

There are many factors during the manufacturing process that leads to waste generation, which needs to be resolved before implementation. The following are some practical examples to review the uncover possible waste factors:

1. Transportation could be minimized by having multiple production sites for the complete production targeted.
2. Don’t go for inventory stock of perishable materials (fruits and vegetables). Aim for just in time production.
3. Always analyze and aim for the correct production number of any product. Dumping the overproduced materials not loved by the consumers may lead to waste generation. (Overproduced bike models which do not sell).
4. Production with zero defects will also reduce the waste production. Always target for zero-error production.
5. Minimize the processing stage; excess processing may lead to undue waste generation.

14.2.2 Managing Wastes: Generation to Final Disposal

Waste management refers to the combination of transporting, recycling, and proper disposal of waste generated by any organization. Waste management provides various ways to efficiently use garbage that do not belongs to trash. There are many methods for waste disposals, among which the most commonly used method by the developing countries is using landfills for disposal. Landfill means burying the waste in land. This method of disposal comes with two major constrains, namely, the requirement of space and air and water pollution. The gases produced by the degradation of dumped materials (mainly methane) cause a lot of air pollution and successively water pollution too. Incineration or burning (also known as thermal treatment) is another disposal system in which municipal solid waste is burn at elevated temperature in order to switch them into remains and vaporized stuff. The principal benefit of this kind of process is that it can condense the amount of solid waste to 25–35% of their initial volume.

Recycling is the practice of converting waste stuff into innovative and new products via expenditure of new raw materials. Recycle is the third component of reduce, reuse, and recycle waste ladder. The thought at the back recycling is to diminish energy consumption, trim down dimensions of landfills, condense water and pollution, condense gas emissions from greenhouse, and hence safeguard our natural assets for upcoming employ.

Plasma gasification is a further variety of waste administration. Plasma is principally an electrically charge and extremely ionize gas. By means of this process of waste clearance, a container uses distinctive plasma torch functioning at 10,000°F and above, which creates a gasification sector of 3000°F for the renovation of solid or liquid waste into syngas.

Composting is a trouble-free and widely accepted biodegradation procedure that takes organic wastes and turns them into nutrient loaded foodstuff for plants. Usually composting is used for organic agriculture and happens by allowing organic supplies to stay at one place for long duration till microbes act upon and decompose them. It is among the most excellent system of waste clearance as it can spin hazardous organic commodities into secure compost. This method is accompanied by two lacunas, space and time constraints.

14.3 Classification of Waste

Waste can be classified in various ways, viz., on the basis of its processing, e.g., recyclable and nonrecyclable, and on the basis of source of origin, e.g., urban wastes, industrial wastes, domestic wastes, e-waste, etc. (Fig. 14.1). Generally health care is a broad area in terms of the types of facilities which can be public or private or semigovernment and government installation. It can be a service industry or research installation in health-care sector, sometimes small home health care for the incurable and long-term disease which produces waste as dialysis, insulin, etc. (Table 14.1) (Hoornweg and Bhada-Tata 2012).

Household waste also called general domestic waste coming from kitchen and housekeeping activities contribute 3/4 of the total solid waste generation. Remaining 1/4 waste is considered to be harmful and commonly called hazardous. Hazardous waste can be responsible for variety of environment and health issues which can lead to health hazards.

Fig. 14.1 Classification of waste

Table 14.1 List of waste generated from health-care facilities

Waste category	Descriptions and examples
Sharps	Injection needle; transfusion sets; scalpel; surgical knives and blades; glass pieces
Infectious	Contaminated body fluids, blood; cultures and microbial stocks; waste including human feces
Pathological	Operated tissues and organs or body fluids; amputated body parts; aborted fetuses
Pharmaceutical, cytotoxic	Expired drugs, cytotoxic, cancer therapy chemicals; genotoxic chemicals
Chemical waste	Laboratory reagents; film developer; disinfectants, heavy metals like lead and cadmium; mercury of thermometers and blood pressure gauges
Radioactive waste	Liquid chemicals from radiotherapy including film development liquid, dyes, etc.
Nonhazardous or general health-care waste	Waste that does not pose any type of hazard for human and environment

14.3.1 Solid Waste Management: Especially Municipal Waste

Municipal waste is part of urban wastes. From year to year municipal solid waste (MSW) has been on the increase across the world. Municipal solid wastes comprise of biodegradable, recyclable, and inert wastes. Such recyclable waste reduces production of raw material for production of these items. The biodegradable waste basically comprises of wastes generated in kitchen which chiefly includes waste food, besides that vegetable and garden wastes are also part of biodegradable waste. Recyclable waste comprises of plastic and paper wastes, glass, metal, and tin can. Recycling is the process where the waste material is used for processing to produce a new product. Other wastes, viz., sand, pebbles, and gravels that are part of building material and generated due to construction or demolition, comprise inert waste.

Management of solid wastes is done on the principle of reduce, reuse, recycle, and reduce (Kasturirangan et al. 2014).

According to recent data, more than 50% waste generated in India is biodegradable. The remaining less than 50% comprises of inert and recyclable wastes. Recyclable waste is less than 20% (approx. 17.5%) and inert includes 31%. Annual municipal solid waste generation in India is about 62 million tons; for dumping, its 340,000 cubic meters of landfills is required. In a decade, we will be short of land to dump this amount of solid wastes without treatment. Dumping solid waste in landfills also has serious health hazards (Kasturirangan et al. 2014).

14.3.1.1 Sewage

Sewage comprises of waste suspended in water, and more than 90% of sewage is water. Management of sewage/wastewater is essential to protect environment general health and well-being. The treatment of wastewater or sewage produces sludge, a semisolid waste material produced during wastewater treatment. Sludge is rich in nitrogen and phosphorus. The treatment process includes various physical and chemical treatments. It contains various hazardous chemicals and also heavy metals and organic matters. It also contains many pathogenic as well as nonpathogenic microorganisms.

14.3.1.2 Construction and Demolition Waste

It is again a solid waste generated during to destruction of old buildings or renovation of private industrial commercial or governmental properties or infrastructure. The waste generated due to these activities can be recycled or reused as such in developing new infrastructure.

14.3.2 Industrial Waste

Waste that is generated from industries includes both hazardous and nonhazardous wastes. These include chemicals, pesticides, fluids used in cleaning, medical wastes, etc.

Hazardous waste can reflect the following characteristics:

Toxic Chemicals that reveal the toxicity at a stage. The chemicals have a pathway to imbibe into blood by the pulmonary pathways and circulate in the whole body.

Corrosive Corrosion due to strong alkali and acids can be dangerous. They can cause harm to skin or eyes. It can lead to permanent damage including poisonous emission.

Explosive Materials which release compressed gases if ignited and can explode with a touch of heat.

Flammable Materials or Compounds who can be ignited easily and have a tendency to burn out with great speed and liberates heat up to great extent.

Chemically reactive Materials so reactive that it can burn with the exposure of atmosphere hence stored accordingly with care and precaution.

Hazardous waste can be divided into the following types (UNEP 2010):

- *Listed wastes*
  Environmental Protection Agency (EPA), USA, has prepared a list of waste, and those that come under this category are called listed wastes.
- *Characteristic wastes*
  Waste that has ignitability, corrosivity, reactivity, and toxicity.
- *Universal wastes*
  This comprises of poisonous metal-containing equipment, e.g., mercury, pesticides, lamps, and batteries.
- *Mixed wastes*
  It contains both radioactive and hazardous waste.
- *Health-care wastes*
  The hazardous nature of health-care waste falls under the following properties:
  - Infectious agents
  - Genotoxic or cytotoxic properties
  - Toxic or hazardous chemical
  - presence of radioactivity
  - Presence of used sharps

14.3.2.1 Mercury

In normal condition, mercury metal remains in liquid form with shining silver color. Mercury can be transported with air currents and accumulates at the bottom of water bodies, which is ultimately converted by bacteria in methylmercury which subsequently enters in food chain.

Hg is useful but can be very toxic or can be fatal in some forms and can be imbibed through dermal pathway. The adverse effect can harm central nervous system, digestive system, and pulmonary system along with failure of renal and immune system. The adverse effect of mercury also includes several types of neurological deformity and developmental deficits during pregnancy (WHO 2005a).

14.3.2.2 Effect of Mercury on Human Health Through Environmental Exposure

Mercury is useful for manufacturing of medical devices especially for diagnosis, but it is a challenge for long-term safe disposal. Batteries used in medical devices for the power are generally using mercury which is again an additional challenge in terms of disposal. The awareness of harmful effects has stopped the use of mercury in batteries in the USA and EU, but still third world countries are using it up to some extent. Health-care facilities have started gradually replacing mercury with other alternatives.

Released mercury in water bodies from untreated wastewater/sewage adds approximately 5% of total mercury pollution to the environment effecting aquatic ecosystem. Once pushed in the aquatic ecosystem, it quickly enters the food chain.

The dental procedures contribute half of the mercurial contamination along with medical incinerators in the environment as per US Environmental Protection Agency in the EU and USA (Sources: Risher (2003) and WHO (2005a)).

14.3.2.3 Silver

Silver is another metal which is being used with more applications in the arena of disinfectants as a bactericide and in advance field of nanotechnology research due to its properties. Silver can demonstrate variety of potential effects on bacterial resistance which will be an additional problem to health-care research and treatment (Chopra 2007; Senjen and Illuminato 2009).

14.3.2.4 Disinfectants

Chlorine and ammonium compounds are used in large quantities in hospitals, pathology, PHC, etc. as antimicrobial agents. It is not advisable to use large quantities in the closed environment because of toxic fumes.

14.3.2.5 Pesticides

The improper storage of pesticides generally creates leakage that trickles down to the groundwater during the rainy season leading to contamination of groundwater and subsequently enters the food chain causing hazardous mutations in the DNA giving long-term effect of genetic defects in human race.

14.3.2.6 Hazards from Genotoxic Waste

The chances of toxicity of genotoxic waste depend on the extent and duration of contact for health-care professional. The exposure may occur during treatment by particular drugs. The main route of exposure is pulmonary or dermal or through food, and bad laboratory practice such as mouth pipetting is also responsible. Infection may occur due to contact with body fluids and secretions of patients of oncology. The cytotoxicity of many drugs affects the processes such as DNA synthesis and cell division. Alkylating agents are cytotoxic at any point in the cell cycle.

Many cytotoxic drugs are potent irritants when come in direct contact with the dermal area and eyes. Side effects of cytotoxic drugs can be dizziness, nausea, headache, or dermatitis.

14.3.2.7 Hazards from Radioactive Waste

Radioactive waste can cause various problems associated with nervous system. It can cause a temporary or permanent sift in the nucleotides of DNA causing either nonfunction of gene or defective expression of genes. The contamination of even low radioactivity substances can happen due to improper storage condition and containers. People in the vicinity are at greater risk.

14.3.2.8 Health-Care Waste Hazard

Specific hazards are posed by different types of health-care waste. There are occupational hazards associated with treatment processes. If poorly operated, it may cause health concerns, associated with increased cardio and pulmonary failure (Fritsky et al. 2001; Matsui et al. 2003; Brent and Rogers 2002; Lee et al. 2002; Segura-Muñoz et al. 2004).

- Physical injury can happen by ash from the incineration and burnt-out needles and glass. Further, ash containing high level of heavy metals supports the synthesis of dioxins and furans at 200 °C–450 °C.
- Autoclave and steam disinfection treatment may cause serious burns due to steam and high temperature if not maintained properly and poorly operated. The elevated concentrations of organic and inorganic compound discharges to sewerage systems should be in regulated limits.
- The equipment used in health-care industry as shredding and compactors can cause physical injury.
- Burial sites situated at wrong place as in densely populated area of the city are threat to the people living in the vicinity. The estimation to measure the potential and amount of risk is difficult to calculate and estimate. The chemical contaminants or pathogens in landfill may infect the groundwater which can affect the aquatic ecosystem which will ultimately affect the food chain. Sites at densely populated areas can pose a threat to the population of smoke and dangerous gases including workers.

14.3.2.9 Nonhazardous Waste

This includes wastes generated by industries and is recyclable. Mostly the large portion of total waste generated by health-care industry is nonhazardous waste. They also can be considered as solid municipal waste, e.g., paper, cardboard and plastics, discarded food, metal, glass, textiles, plastics and wood, etc. The wastes composition is a characteristic of health-care industry. In the past, the waste was buried at the dumping sites or burnt in the open air. But nowadays major awareness regarding proper disposal has compelled for the safe disposal. Most of the nonhazardous waste is recyclable such as paper, plastic, cardboard, wood, and metal articles, hence managing the general waste.

There are no clear guidelines for the disposal of the general waste and its classification. The understanding of the transmission of disease is important to prevent the spread of disease. The infection requires sufficient potential to cause disease also called as virulence including mode of transmission. Some countries have a proper SOP for collection, transportation, and disposal, whereas some countries are not even having the proper container and proper protection for the persons handling.

14.3.3 Plastic Waste

The term plastic is used for polymers of high molecular weight substances, which can be synthetic or semisynthetic, mostly derived from petrochemicals. They may be partially natural also. Plastic products have become a basic need in our day-to-day life. Approximately more than 10 million tons of plastic products are being processed and consumed every year. The plastic industry has seen phenomenal growth since the beginning of polystyrene production in 1957. Because of being lightweight and durable, plastic has most versatile uses, thus becoming ubiquitous in its presence. Plastic has entered in every spectrum of daily use, such as grocery, shopping and garbage bags, packaging and wrapping material, storage containers, household products, toys, and even clothing. Also it is frequently utilized as protective packaging for mobiles, appliances, furniture, medical devices, etc. Around 1 trillion plastic bags are used worldwide each year, and maximum of these items end up in landfills, dumpsites, and water bodies. Domestic plastic consists of majorly polythene bags, bottles (soft drink, water, or shampoo), and lids. In agriculture and horticulture, plastic is employed for food grains' storage and transportation, irrigation pipes, etc. and has replaced jute bags and glass in storage and packaging. The use of plastic in roads, railways, and shipping infrastructure has been in pipes, wires, cables, waterproofing membranes, wood PVC composites, etc. The increase in domestic consumption of plastic has increased its potential for plastic industry worldwide. At industrial level, plastics have made significant contribution in automobile, electronics, health care and pharmaceuticals, construction, textiles, and FMCG sectors. Many newer applications of plastic have also emerged like reinforced thermoplastic with corrosion and chemical resistance, vacuum packaging, textile fibers which can regulate body temperature and are resistant against bacteria, tough plastic bags with enhanced storage life, and so on. The plastic industry is growing at a rate of 10% and has reached 100,000 crores business by 2015.

Plastic constitutes almost 10% of household waste, which was more than 250 million in 2007 (Verma et al. 2016). This consumption and production of waste are increasing also with each year (UNEP 2009). Plastic is a crude polymer of carbon and thus takes years to decompose completely. Therefore they are said to be non-biodegradable, and the time for their complete removal is estimated to be hundreds to thousands of years (Kershaw et al. 2011). According to UN map of ten rivers worldwide to carry plastic waste into oceans, the Ganga-Brahmaputra-Meghna river system is among them, with the threatening effects on marine life and even microplastics in drinking water. With the increase in plastic use in every minor or major field in emerging and developing economies, this problem of plastic waste generation, its management, or recycling would require additional focus (Table 14.2). According to the overview of plastic waste management report (2013) by Central Pollution Control Board, India, there are a number of environmental concerns due to indiscriminate littering and recycling of these non-biodegradable wastes. Such improper disposal leads to contamination of groundwater, changes in microbial flora of soil, and increase in poisonous compounds in the atmosphere, posing grave multidimensional problems, like serious health issues in human beings as well as animals, when these stray cattle feed on throwaway plastics (Fig. 14.2).

Table 14.2 Some of the most plastic-polluted rivers of the world (Schmidt et al. 2017)

River	Location	Reason
Yangtze River	The longest river of Asia, going into East China Sea near Shanghai	Highest in flowing the most plastic waste into oceans
Indus River	One of most important rivers of Indian subcontinent, reaching the Arabian Sea	Carrying highest amount of mismanaged plastic debris
Yellow River	Also known as "China's sorrow," it is the second longest river	With more than 25% fish species extinct, river is almost non-potable now
Hai River	Connects Tianjin and Beijing and runs into the Bohai Sea	High population density without proper disposal system
Nile River	This longest river flows through 11 countries before reaching Mediterranean Sea	Though it dries up during summers, it still carries enough plastic into the sea
The Ganges	Most important river of North India, it reaches Bay of Bengal	Unmanaged and unchecked domestic as well as industrial waste disposal has made it one of India's most polluted rivers
Niger River	This is Western Africa's major river. Reaches into the Atlantic Ocean.	Construction and oil spills along with plastic pollution causing major water contamination
Mekong River	The river covers a distance of more than 2500 miles and flows through Southeast Asia, including Vietnam and Laos	Responsible for dumping most of 8 million tons of plastic reaching seas

Fig. 14.2 Waste generated by plastic bottles and percentage of recyclable plastic waste

14.3.3.1 Environmental Contaminants of Plastics: Phthalates, BPA, etc.

BPA or bisphenol-A and phthalates are commonly called everywhere chemicals due to their frequent and common use in making everyday plastic products, viz., bottles, disposable utensils, personal and baby care products, and toys. BPA is used in hard, clear plastic, whereas phthalates make plastic flexible. Both these substances are known to percolate or leak from plastic into food and liquid and finally into our system. Much scientific evidence suggests BPA and phthalates are associated with many hormonal and developmental problems. Infants and young children, who are vulnerable during early developmental years, are likely to be at potentially most risk from exposure to "everywhere chemicals" such as BPA and phthalates.

BPA, a neurotoxin and endocrine disruptor, has been found to be harmful in many experimental studies. Also a comprehensive study on BPA and its related harmful effects on human beings has reviewed more than 90 similar studies showing correlation of BPA with health. This published work by Rochester (2013) had outlined the association of BPA exposure with many health issues, like reproductive and developmental effects, metabolic diseases, and even behavioral effects in children. A number of works have now demonstrated correlation between phthalate and BPA exposure with altered levels of steroid hormone in adults (Ehrlich et al. 2012; Sathyanarayana et al. 2017) and also in infants (Araki et al. 2014; Lin et al. 2011). BPA and phthalate exposure in utero may also alter female reproductive development (Watkins et al. 2017). Therefore it becomes pertinent that phthalates and bisphenols are regularly monitored in various environmental and biological samples. The conventional methods include separation and spectrometric techniques; however modern electroanalytical methods and other analytical methods with high sensitivity, selectivity, easy automation, low investment, and running costs for large-scale monitoring are the need of the hour.

14.3.3.2 Plastic Waste Management

The excess use of plastic materials nowadays is serious worldwide environmental and health concern. Disposal of plastics waste has drawn attention of environmentalist due to their non-biodegradability and unscientific disposal with possible leaching to contaminate soil, subsoil, and water. Also, the unchecked littering and nonscientific processing of plastic waste is becoming a major problem. Such waste eventually reaches water bodies through drains and rivers. The waste plastic is either recycled or dumped in landfills or dumpsites. However, the high cost and decreased space for dumping are major deterrent factors forcing government agencies and environmentalists to find out alternative options for plastic waste disposal (Zia et al. 2007).

Plastic recycling, despite being effective alternative, is more difficult than glass, paper, or metals. Because different varieties of plastic would contain different polymers which may have different properties or melting temperature, one uniform recycling process cannot be employed. This also makes proper separation of plastics necessary. According to physical properties, plastics are broadly categorized as (i) thermoplastics, which are of hard or tough elasticity and can be melted, (ii) elastomers are soft and elastic but cannot be melted, and (iii) thermosets, which are of hard elasticity range and can't be melted. But the recycling of plastics also has several limitations and is found to be more harmful to the environment than its virgin counterpart because different colors, additives, stabilizers, and flame retardants are mixed during recycling process and it can be repeated for two to three times only. After every recycling, the strength of plastic material is also reduced due to thermal degradation. The Central Pollution Control Board of India in its 2013 report states that indiscriminate and unskilled recycling or reprocessing is also causing a number of environmental issues, with many fugitive emissions released during polymerization process. The toxic gases, like CO, Cl (chlorine), HCl, dioxin, furans, amines, nitrides, styrene, benzene, 1, 3-butadiene, carbon tetrachloride, acetaldehyde, etc., are released during burning of plastics, causing many environmental and health issues. Also unchecked dumping of plastic waste on land is rendering the soil infertile and poses serious aesthetic issues in the surroundings. Therefore, it is better to reuse the plastic products rather than recycling them. This will save much energy and resources.

14.3.3.3 Recycling of Plastic

The recycling of plastic is being done in effective manner now, and the plastic industry has developed many technologies which can effectively treat and recycle waste from discarded products. More than hundred thousand tons of polyethylene from discarded plastic is being converted into various parts of textiles (Gobi 2002). According to European Union's report of 2007, UK alone has recycled ≈250,000 tons (almost 95%) of plastic waste (EA 2008). There are four major classes in plastic waste treatment and recycling process: re-extrusion (primary), mechanical (secondary), chemical (tertiary), and energy recovery (quaternary; Mastellone 1999).

In re-extrusion, which is the primary recycling, the plastic scrap and industrial or single polymer plastic are reintroduced to produce products of the similar material. This process utilizes scrap plastics that have similar features to the original products (Al-Salem et al. 2009a). However, this process is not very favorable with recyclers as it can make use of only semi-clean scrap.

The secondary recycling, which is the most preferred and widely used mechanical recycling method, involves reusing the plastic to manufacture plastic goods through mechanical means (Mastellone 1999). In mechanical recycling, first the plastic is reduced or resized to a more suitable form like pellets, powder, or flakes. It can be achieved by milling, grinding, or shredding (Zia et al. 2007); however it can recycle only particular type of polymers, e.g., polyethylene terephthalate (PET) and high-density polyethylene (HDPE) bottles have high recyclability, whereas polyvinyl chloride (PVC) and other materials have limited recyclability due to very high chlorine content in PVC and other harmful additives. Since mechanical recycling requires particular type of plastic, segregation and cleaning such plastic waste increase the operational cost. Mechanical recycling process has been employed to produce many recycled products, like grocery bags, pipes, shutters, etc. The only limitation with this process is its old design components and thus release of harmful gases. Also the laminated plastics and carry bags still remain the challenge for the process and thus have become an important issue in R&D.

The most advanced technology in plastic waste recycling is chemical or tertiary recycling which employs conversion of plastic materials into smaller molecules, usually liquids or gases, suitable as a feedstock for the production of new petrochemicals and plastics (Mastellone 1999). The chemical recycling process includes pyrolysis, gasification, liquid-gas hydrogenation, viscosity breaking, steam or catalytic cracking, and the use of plastic waste as a reducing agent in blast furnaces. PET and nylon, the condensation polymers, undergo degradation to produce monomer units, i.e., feedstock (Yoshioka et al. 2004), while vinyl polymers such as polyolefins produce a mixture containing numerous different components to be used as a fuel.

If plastic waste cannot be recycled due to economic or any other constraints, it can be utilized for energy recovery. Energy recovery is the process where waste is burnt to produce energy in the form of heat, steam, and electricity. This process can be very useful in plastic waste treatment as plastics possess a very high calorific value when burned and produce water and CO_2 like any other petroleum-based fuels (Dirks 1996). If incineration of nonrecyclable plastics is performed with high-efficiency energy recovery, less CO_2 is released than by disposing plastic waste in landfills. However, in developing countries, cost-effectiveness of investing in incineration infrastructure must be assessed to ensure financial sustainability in the long term. Also the environmental concerns are associated with burning plastic waste, because of emission of many air pollutants such as CO_2, NO_x, and SO_x as well as volatile organic compounds (VOCs), smoke (particulate matter), and heavy metals. Carcinogenic substances (polycyclic aromatic hydrocarbons (PAHs), nitro-PAHs, polychlorinated dibenzofurans, dioxins, etc.) have been identified in particles from combustion of synthetic polymers such as polyvinylchloride (PVC), polyethylene terephthalate (PET), polystyrene (PS), and polyethylene (PE; Al-Salem et al. 2009b).

To date about 75 countries in the world have taken actions to reduce the consumption of plastic bags, either by total ban on use and sell of plastic bags or by levying fee on retailers and consumers (UNEP 2017). However, mixed policy of total ban on thin plastic bags and levy on thicker ones has been quite effective in reducing plastic use in many countries, including India. However, plastic waste is derived from oil and has a recoverable energy; thus it is important to consider recycling and energy recovery methods in plastic manufacturing and converting facilities. Many technologies have shown promising results and need further research and development in this area.

14.3.4 Electronic Waste

Electronic waste also called as e-waste is basically the bulk of unwanted electronic items that have exceeded their shelf time. Some examples of the items that contain harmful toxic components that need to be recycled are cell phones, batteries, monitors, TV scenes, stereos, etc. Electronic waste may account for a lesser percentage of trash in landfills but constitutes for a higher percentage of toxic garbage. Products that contain maximum electronic items are the main source of generation of e-waste (computers). E-waste has both the components – hazardous and nonhazardous substances. The hazardous components include plastics, mercury, lead, arsenic, and cadmium which pose high amount of risks to human health. Often the people who are mainly involved in the recycling and recuperation of the e-waste are more prone toward the chronic diseases like cancer.

Technology is changing every day, and as a result electronic equipments are discarded in abundance both in rising countries and also in the developed countries. The decreased self-time of electronic items and the affordable price of new

Table 14.3 Various categories of e-wastes

S. No	Categories of e-waste	Percentage contribution of total e-waste
1.	Consumer electronic televisions, VCR/DVD/CD players, radios, CCTV cameras, etc.	21
2.	Large household appliances like refrigerators, air conditioners, dryers, washing machine, etc.	49
3.	Lightening equipments like fluorescent bulbs, tube lights, halogens, sodium lights, etc.	3
4.	Other equipments like sewing machines, electric saw, treadmills, medical devices, etc.	4
5.	Small household appliances like coffee machines, irons, toasters, vacuum cleaners, electric kettles, geezer, toys, automatic dispensers, etc.	7
6.	Telecom equipments and computer-related equipments like fax machine, PCs, laptops, mobiles, earphones, mouse, printers, scanners, etc.	16

Table 14.4 Hazardous compounds present in e-waste

S. No.	Components	Hazardous compounds in them
1.	Polymers and plastics	Teflon and PVC as polymers, Cd, Pb, phthalates as additives
2.	PC boards (printed circuit as boards) and toner cartridge, batteries	Sn in solder, Pb, Be, and Hg in switches and contacts, As in LEDs, Ni and Cd in batteries, tonner carbon black ink
3.	Capacitors containing PCBs and refrigerating circuits	PCB and Feron
4.	LCDs (liquid-crystal displays)	Liquid crystals in the screen
5.	CRTs (cathode-ray tubes)	Sb and Pb in CRTs, Ba in electron gun

technologies with advanced features have led to the enormous creation of e-waste. This e-waste generated offers a good opportunity to the secondhand sale of electronic item industries. These e-wastes are categorized according to their properties (Table 14.3).

The imminent presence of various heavy metals in the e-waste makes it very difficult to degrade and possess high risk to the surroundings as well as human well-being. Adding on, the people occupied in the management, shipping, and clearance of these wastes are directly exposed to these hazardous elements. The manufacture of majority of equipment is PCB based which in turn contains high number of dangerous compounds like stibium, lead, arsenic, gallium, mercury, and cadmium. The list of hazardous compounds found in various wastes is listed in Table 14.4.

There is a compatible e-waste management system that encompasses compilation, storage, recycling, reclaim, incineration, and reuse of the waste generated. The following is the schematic diagram for the first step in a typical e-waste recycling process (Fig. 14.3).

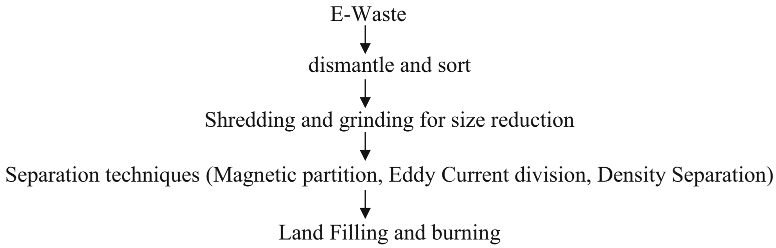


Fig. 14.3 Schematic representation of e-waste recycling process

14.3.5 Biomedical Wastes

Knowledge and awareness about health-care wastes have now become more prevalent among the government, medical practitioners (private), and civilians. Medical staff and administration have to be more attentive and responsible in the collection and disposal of waste. Improper handling practices should be discouraged, and the concerned person should ensure the proper parking of waste at proper place in a proper manner. The responsibility of each and every person related to health-care industry should follow the SOP of disposal till end.

The characteristic feature of each health-care industry produces waste pose to patients, staff, and the environment, guiding regulatory principles for developing local or national threat approaches for health-care waste management and converting into action plan for regions and individual health-care facilities. Specific technologies are described for waste minimization, segregation, and treatment. The advantage and disadvantage of each technology including environmental characteristics need to be acquired.

The wastewater treatment must be connected to difficulties of handling health-care wastewaters and generation of new guidelines on the various wastewater treatment options to central sewage systems. The awareness and training regarding occupational safety, hygiene, and infection control should be made for general population.

14.3.5.1 Generation of Health-Care Waste

Knowledge of quantity and types along with the storage conditions and disposal techniques are must to understand before safe disposal. Generation of waste and the quantity estimation will allow to predict the capacity, type, storage, and transportation of containers as well as the storage area of these containers (Fig. 14.4). It will further increase revenues from recycling, controlling the waste quantity, and improving the environmental conditions.

The assessment of waste will provide an opportunity to increase efficiency of current practices, which will give a more efficient option of saving the cost involved. Cost-effective recycling will be beneficial in two ways: one by cutting cost of recycled goods and another by saving cost of manufacturing new goods which

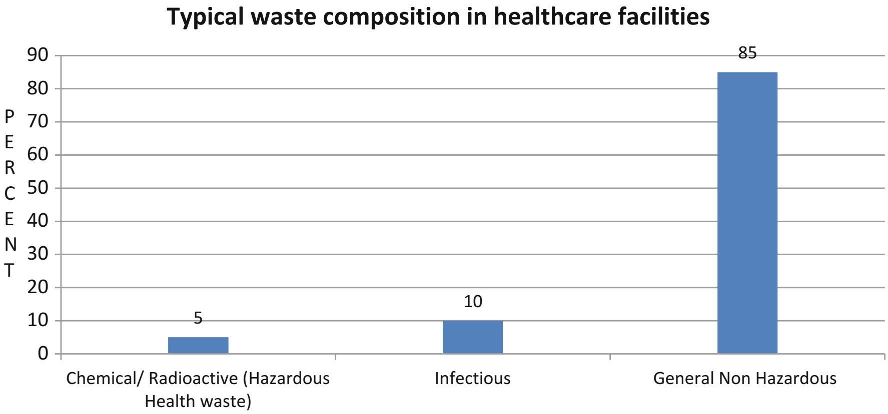


Fig. 14.4 Categorization of biomedical wastes

will again pose a threat to the environment by increasing quantity on the globe and cause environment degradation.

The waste-assessment program can be of different approaches as estimation of waste generation per bed is done by collection of waste segregated in separate containers and weighed from different areas divided by number of beds in the area regularly. Calculation and data collection for a longer period are essential to accurately estimate considering seasonal variation and prevalence of an epidemic with respect to normal days. This also reveals the generation of waste capacity facility wise and individual parts of a facility.

Survey of the staff is the other way for the assessment of quantification of waste. The questionnaire asking staff reveals the information regarding the measurements of facilities to estimate waste quantities. When extrapolating the data, the sample size is always taken into account and facility size.

14.3.5.2 Factors Affecting the Waste Generation

Generation of waste is measured in terms of occupied beds, patients per day, department, location, regulations on waste classification, segregation practices, temporal variations, and infrastructure development of the country.

In rural and urban areas, the health-care facilities may be different in services, size, complexity, and resources including number of medical and staff. Regulations on types of waste and segregation practices affect waste generation rates.

Comparison of waste data from other countries may be used with care because the variation within the country may be tracked and monitored for various conditions also. The different types of establishments should also be taken into account.

14.3.5.3 Physicochemical Characteristics

Development of waste minimization plan is essential and associated with physicochemical composition of health-care waste. Composition of waste is the deciding

Table 14.5 Types of infections causative organisms and transmission vehicles found in waste

Type of infection	Examples of causative organisms	Transmission vehicles
Gastroenteric	*Salmonella*, *Shigella* spp., *Vibrio cholerae*, *Clostridium difficile*	Feces and/or vomit
Respiratory	*Mycobacterium tuberculosis*, measles virus, *Streptococcus pneumonia*	Inhaled secretions, saliva
Ocular	Herpesvirus	Eye secretions
Genital	*Neisseria gonorrhoeae*, herpesvirus	Genital secretions
Skin	*Streptococcus* spp.	Pus
Anthrax	*Bacillus anthracis*	Skin secretions
Meningitis	*Neisseria meningitidis*	Cerebrospinal fluid
AIDS	Human immunodeficiency virus (HIV)	Blood, sexual secretions, body fluids
Hemorrhagic fevers	Junin, Lassa, Ebola, and Marburg viruses	All bloody products and secretions
Septicemia	*Staphylococcus* spp.	Blood
Bacteremia	Coagulase-negative *Staphylococcus* spp. (including methicillin-resistant *S. aureus*), *Enterobacter*, *Enterococcus*, *Klebsiella*, and *Streptococcus* spp.	Nasal secretion, skin contact
Candidaemia	*Candida albicans*	Blood
Viral hepatitis A	Hepatitis A virus	Feces
Viral hepatitis B and C	Hepatitis B and C viruses	Blood and body fluids
Avian influenza	H5N1 virus	Blood, feces

factor for efficient waste disposal. Physicochemical parameters in low moisture content in waste advocate the use of microwave in treatment technology.

Estimate of storage capacity, transport mode and condition, treatment chamber capacities, as well as output of the compactors, shredders, and other size reduction equipment is required.

14.3.5.4 Overall Management of Health-Care Waste

Personnel dealing with waste should be trained and be made aware of the main categories of health-care waste specified in national or local regulations. The officers should conduct regular inspection of the facility to identify the medical areas that produce waste. Assessment and observation with the support of survey and questionnaires will help in providing data to identify problems and rectification (Table 14.5).

The poor management of waste can sometimes lead to human immunodeficiency virus and hepatitis viruses B and C. These infections are further transmitted to the mass population unknowingly. For example, if a patient admitted in hospital comes in contact with the HIV-infected needle due to carelessness and poor waste disposal practice which can infect the population in the family by the contact of body fluid, the family members then further start chain reaction in the society (Source- Puro et al. 1995; Trim and Elliott 2003; Ganczak et al. 2006).

Cuts from sharps can infect these wounds if they are contaminated with pathogens. Poor management of waste handling is the main cause of microbial resistance to the drugs and disinfectants (Source-Novais et al. 2005).

Hazards from Chemical and Pharmaceutical Waste

The expired drugs or outdated chemicals and pharmaceuticals are disposed off as waste. Their toxicity can be manifested in the skin and mucous membranes through inhalation or ingestion by contact with flammable, corrosive, or reactive chemicals.

Occupational exposures of some workers had been reported as infection to the CDC from blood, body fluids, and laboratory specimens containing HIV and are considered as occupational threat. Spread of hepatitis B in Gujarat in 2009 is the case of the reuse of injection equipment (Harhay et al. 2009).

Impacts of Genotoxic Waste

Data on long-term health impacts of genotoxic health-care waste are scanty due to non-certainty of type of compound to which human are exposed.

Handling of antineoplastic drugs, manifested by increased urinary levels of mutagenic compounds in exposed workers and an increased risk of abortion. Exposure of staff while cleaning of urinals poses potential danger.

Impacts of Radioactive Waste

Many incidents resulting from improper disposal of radioactive waste have been regularly reported. In Brazil the shifting of health-care facility dealing with radioactive waste was ignored the old premises leading to leakage of radioactivity causing carcinogenic impact on the general population. Some people got access to the old facility was exposed the radioactive waste in revealing it due to curiosity.

Survival of Pathogenic Microorganisms

Pathogenic microorganisms can survive up to a certain extent. Ability of specific microbes and their resistance to environmental conditions, such as temperature, humidity, ultraviolet irradiation, availability of organic substrate material are the key variables.

Hepatitis B virus can survive in discarded needles for up to 7 days resistant to slight exposure to boiling water and will be viable for up to 10 h at a temperature of 60 °C and also can survive exposure to 70% ethanol.

HIV can survive for 15 min with 70% ethanol and only 3–7 days at normal condition but became nonfunctional at 56 °C. Prions are the agents of degenerative neurological diseases that are very resistant like viruses (Johnson et al. 2006 and Saunders et al. 2008).

Due to antiseptics in the health-care waste, they are not good media for the survival of pathogens in the health-care industry; ironically it sounds unusual as the microbial load is very low. The survival and spread of pathogenic microorganisms by rodents, insect, flies, and cockroaches, generally feed or breed on organic waste.

Need for Further Research and Epidemiological Surveys

At national and international level, an organization dealing with health-care waste should devise a universal SOP and guidelines for the collection of data starting from village to international scale. This uniform data collection technique will give a broader picture of the waste management status at national and global level at the same time. This will help in predicting of spread of epidemic or pandemic in the country or globally.

The monitoring and collection of information and creation of a database would lead to control outbreak recognized and investigated. It also provides a basis for introducing control measures, assessing their efficacy, reinforcing routine preventive measures, and determining avoidable infection.

14.4 Waste Policy

14.4.1 National Policy

Policy should be able to support demands and rectify the problems in the country, considering the international agreements and conventions adopted to govern public health and sustainable development.

National policy legislation for health-care waste governance is essential. Effective regulations should be capable of fulfilling the expectation and need of health-care staff and reinforce for their implementation. Professional organizations must provide official regulations with practical guidelines, codes of best practice. A national policy must be capable to handle regional differences in community pertaining to socioeconomic conditions (WHO 2005b).

14.4.1.1 Guiding Principles

Five principles are used for the effective and controlled management of wastes as mentioned below.

The principle called as "polluter pays" states that all producers of waste are legally responsible for the safe and environmentally sound disposal failing to which liability can be fixed to the party that causes damage.

The principle called as "precautionary" is defined under the Rio Declaration on Environment and Development (UNEP 1972) named as Principle 15. "Where there are threats of serious or irreversible damage to the environment, lack of full scientific certainty should not be used as a reason for postponing cost-effective measures to prevent environmental depletion."

The principle called as "duty of care" translates that the responsibility of the person handling and managing hazardous wastes and related equipment is to ensure use utmost care. It can be achieve with the cooperation of all the parties involved.

The principle called as "proximity" suggests that treatment and disposal of hazardous waste take place at the closest possible location to its source to minimize the risks involved in transport. Every community should be aware, encouraged, and equipped with the facility to recycle the waste it produces, inside its own territories.

The consent principle called as "prior informed" embodied that the information regarding the risk involved should be circulated in the community well in advance with permission of the stakeholders. It can be applied to the transport of waste and the setting up of waste treatment and disposal facilities.

14.4.2 International Policy

14.4.2.1 International Agreements and Conventions

The below-mentioned international agreements and conventions are particularly related to the waste management, environment protection, and sustainable development,

14.4.2.2 The Basel Convention

The Basel Convention means the Control of Transboundary Movements of Hazardous Wastes and Their Disposal and is the most comprehensive global environmental treaty on hazardous wastes. It has 170 member countries globally and aims to protect human and environment against the adverse effect of generation, management, transboundary movement, and disposal of hazardous and other wastes.

The Basel Convention basically is about the transport cross boundary after prior information and consent. Each party is required to follow national or domestic legislation to prevent punishment and legal action. In addition, the convention obliges its parties to ensure that hazardous and other wastes are managed and disposed of in an environmentally sound manner. It also ensures the minimum waste generation and transport in the benefit of the environment. Strong controls are used from movement to storage, transport, treatment, reuse, recycling, recovery, and final disposal.

The Basel Convention consists of:

Y1 – Clinical wastes from hospitals, medical centers, and clinics
Y3 – Waste drugs and medicines

In convention, hazardous characteristics are defined as "H"– infectious substances which contain viable microorganisms, toxins. The convention has *Technical Guidelines on the Environmentally Sound Management of Biomedical and Healthcare Wastes (Y1; Y3)* (UNEP 2003).

The Basel Convention is modified by regular Conference of the Parties, e.g., to prohibit hazardous waste shipments from industrialized to developing countries.

14.4.2.3 The Bamako Convention

The Bamako Convention is based on the import into Africa and the control of transboundary movement and management of hazardous wastes within Africa.

Organization of African Unity at Bamako, Mali, in January 1991 is a consortium of 12 countries and came into force in 1998. Bamako Convention arose from criticism of the failure of the Basel Convention to prohibit trade of hazardous waste to less developed countries and from the realization that many developed nations were exporting toxic wastes to Africa. The Bamako Convention is much stronger in prohibiting all imports of hazardous waste. In nutshell it is a form of Basel Convention to save the interest of African countries and their environment.

14.4.2.4 The Stockholm Convention

Stockholm Convention is global treaty to protect human health and environment against persistent organic pollutants (POPs). These are the chemicals that stay in the environment for long periods, are widely distributed, generally accumulate in the fatty tissue of living organisms, and are toxic to living beings.

Especially polychlorinated dibenzo-p-dioxins and dibenzofurans released to the environment by medical waste and other combustion processes. Governments must ensure best available techniques and promote best environmental practices (UNEP 2006) released in 2006 to prevent the emission of POPs to the environment.

14.4.2.5 Conferences

Various conferences, viz., United Nations Stockholm Conference 1972 followed by World Commission on Environment and Development 1980, World Summit on Sustainable Development in Johannesburg in 2002, and Earth Summit (2012), were held where various plans have been drawn to safeguard the environment.

14.4.2.6 Transport of Dangerous Goods

According to the United Nations Economic and Social Council's Committee transport dangerous goods from developed to transports through developing countries. Not applicable to the bulk transport through sea route of dangerous goods through very large carriers.

It is expected that governments, intergovernmental organizations, and other international organizations are responsible and will conform to the principles of these model regulations, thus contributing to global equality. The model regulations which are mandatory do not apply to the bulk transport of dangerous goods in seagoing or inland navigation bulk tank vessels.

14.4.2.7 Economic Commission for Europe

The international carriage of dangerous goods by road was framed in Geneva on 1957 under the auspices of the United Nations Economic Commission for Europe (UNECE 2010). It came into force in 1968. There were 43 signatories, covering countries in the European Union and beyond.

The ADR's structure is consistent with that of the UN recommendations on the transport of dangerous goods; model regulations; the international maritime dangerous goods code; and the technical instructions for the safe transport of dangerous goods.

14.4.2.8 Aarhus Convention

The Convention is on information accessibility, public participation in decision-making, and justice in environmental matters that came in the existence in 1998 at Fourth Ministerial Conference in the "Environment for Europe" process. It is not only an environmental agreement; it is also a convention about government accountability, transparency, and responsiveness. The Aarhus Convention grants the public rights and imposes on parties and public authorities' obligations regarding access to information and public participation with access to justice (UNECE 2000).

14.4.2.9 World Health Organization

The WHO policy 2004, safe health-care waste management, recommends that countries should adopt the strategies outlined below.

14.4.2.10 Short-Term Strategies

Syringe components using the same plastic to facilitate recycling

Selection of PVC-free medical devices

Identification and development of recycling options wherever possible (e.g., for plastic, glass)

Research into, and promotion of, new technology or alternative to small-scale incineration

Developing countries are safer for the environment and health require operation of incinerators including waste reduction, waste segregation, relocating incinerators away from populated areas, satisfactory engineered design, construction, periodic maintenance, staff training, and management.

14.4.2.11 Medium-Term Strategies

Further, efforts should be made to reduce the amount of hazardous health-care waste that needs to be treated and the research to reveal the health effects of chronic exposure to low levels of dioxin and furan and effective levels in the environment. Risk associated with incineration and exposure to health-care waste should be assessed properly and with utmost care.

14.4.2.12 Long-Term Strategies

Scaled-up and promotion of non-incineration technologies for disposal prevent the disease burden from:

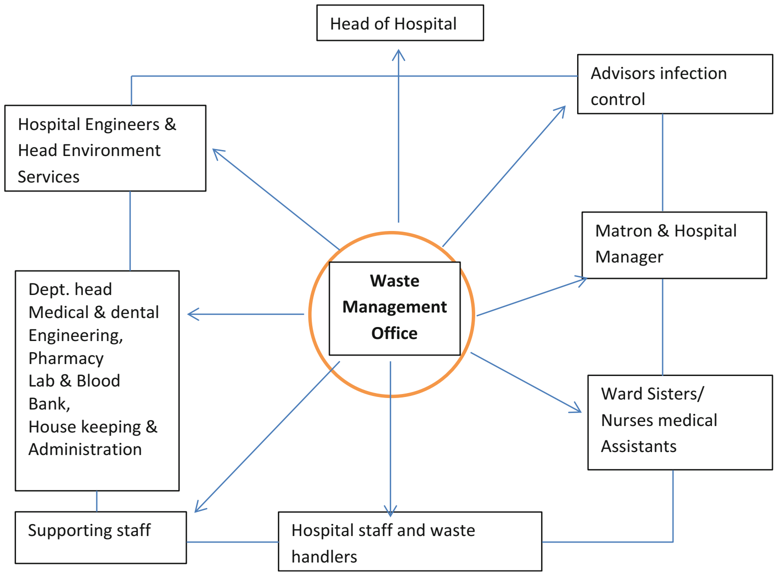
(a) Unsafe health-care waste
(b) Dioxins and furans challenges

Government should develop and implement a national plan, policies, and legislation on health-care waste.

The organizations should promote sound health-care waste management, develop innovative solutions to reduce the volume and toxicity of the waste, and help by investment in the sector for development and growth.

14.4.2.13 International Solid Waste Association

The International Solid Waste Association is recognized as an international, independent, and nonprofit-making association, working in the public interest to promote and develop sustainable waste management globally.



14.5 Recommendations and Future Waste Management

Charging from customers for the food they throw to the conversion of waste into energy resulted in change of attitude toward waste disposal. The model of make, use, and dispose has to be circularized to make, use, degrade, and reuse. This circular thinking and implementation can help to solve the problem of the hour – waste handling.

Converting waste into energy like biogases, biofuels, and novozymes (an enzyme-based solution that converts low-grade oils and cooking oils into biodiesel) is an attractive initiative. Another important aspect is the recyclability of certain products like plastics. Identification of one plastic polymer from another is very challenging and hence their recyclability. All the developing countries need to ratchet up the recyclability procedures. Further, the attitude of people needs to

Table 14.6 Various bioinformatics concepts applied in bioremediation processes

S. No	Area of study	Examples
1.	Proteomics	Detection of key proteins involved in the response of microorganisms in a particular physiological status Identification of up- and downregulated proteins in reaction to the occurrence of specific pollutants
2.	Genomics	Identification of genes involved in biodegradation process and their amplification
3.	Systems biology	Studying the interactions of different genes and proteins inside a system (organism) for their correlation in degradation process
4.	Computational biology	Gene identification, mutational studies, gene mapping, structural modeling for genes identified for biodegrading process
5.	Phylogenetic analysis	Evolutionary relationship analysis of 16s rRNA sequences of dye degrading strains
6.	Molecular docking	Docking studies of dyes with their inhibitor enzymes, enzyme dye-binding profile study

change drastically for waste generation. Convincing consumers for not ending up their food in bins can bring a great change in the waste generation.

Bioremediation is the emerging green technology of environment conservation by eradicating, transforming, and infringing of various contaminants, particularly by harnessing the potential of microbes for degradation of xenobiotic compounds. Bioinformatics, which is an amalgamation of biology and information science and centrally deals with the computer-based examination of large data sets, has taken a new dimension with the introduction of field of bioremediation. There are many significant concepts of bioinformatics which could be applied in the field of bioremediation, namely, the study of microbial proteomics, systems biology, genomics, and computational biology. The highlights of impact of bioinformatics in waste treatment by means of bioremediation are summarized in Table 14.6

There is a strong need to shake up the waste industry, for recycling process, and to counsel the consumers hand in hand for proper future waste management process to observe the sustainable development.

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