Chapter 4
Health-Care Waste Management

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Abstract Health-care waste (HCW) is the term used to describe all waste generated by health-care facilities, laboratories, and research facilities. HCW is largely non-hazardous, with an 85% recycling rate comparable to household waste. The remaining 15% is considered a hazardous material, which can be infectious, chemical, or radioactive. Measures to ensure safe and environmentally sound management of HCW must be implemented to avoid the release of chemical or biological hazards, including drug-resistant microorganisms that could harm patients and health-care workers and the general public. When HCW is not properly handled and disposed of, there is a serious risk of secondary disease transmission to waste pickers, waste workers, health-care workers, patients, and the community as a whole. Sources, generation, compositions, and risk factors for HCW are addressed in this chapter. Discussions on appropriate treatment technologies and their applications in selected countries follow the introduction of the concept of 3R's (reduce, reuse, recycle). HCW management's legal framework, regulations, and code of conduct are also highlighted. At the end of the chapter, the Covid-19 pandemic's effects on HCW management are also discussed.

Keywords Health-care waste · Composition · Waste hierarchy · Incinerator · Covid-19

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Abbreviations

BEP	Best environmental practices
CBMWTF	Common biomedical waste treatment facilities
CW	Clinical waste
EU	European Union
HCW	Health-care waste
HCWGR	Health-care waste generation rates
HDPE	High density polyethylene
LDPE	Low density polyethylene
PETE	Polyethylene terephthalate
PP	Polypropylene
PVC	Polyvinyl chloride
RMW	Regulated medical waste
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

4.1 Introduction

Health-care waste (HCW) is defined as any solid waste generated during human diagnosis, treatment, or immunisation processes. HCW waste includes items such as wipes, gloves, paper towels, syringes, needles, bandages, or dressings containing small amounts of dry blood or fluid, and any other medical waste. Health-care waste is generated by a variety of health-care facilities, private offices, home health-care, clinical laboratories, and research laboratories. The safe management of HCW is seen as a challenge due to its vast volume of production, substantial negative health and environmental effects, and high disposal costs. The generation of HCW has rapidly expanded as the number of health-care facilities and advanced medication in health-care centres has increased. Throughout the world, numerous research is being conducted to define good practice guidelines and provide the best options for proper HCW disposal with the least amount of risk to human health and the environment. Although substantial progress has been made, more has to be done to reduce infectious dangers and contamination of the environment. Despite the severe health dangers and potential environmental damage, HCW management has received little attention in poor countries. A comprehensive waste management plan requires knowledge of the sources of HCW generation and how these wastes are addressed at the source. A proper HCW management requires proper focus on the followings (1) generation and minimisation; (2) source separation and segregation; (3) identification and labelling; (4) handling and storage; (5) safe transportation; (6) treatment; (7) residue disposal; (8) occupational safety and health; (9) public and environmental health; (10) research and development into improved technologies and environmentally friendly practices. It is also necessary to have appropriate guidelines for securely disposing of HCW under local conditions in each country.

4.2 Definition and Classification of Health-Care Waste (HCW)

4.2.1 Terminology

In broad terms, HCW can be classified into the following categories:

1. Solid waste from non-sharp items contaminated with human fluids or biological material which may include clothes, gloves, pipettes, or tissue culture.
2. Liquid waste which includes large amounts of blood or body fluids.
3. Sharps waste includes any material that can puncture or penetrate the skin and is tainted with biological material that could spread or be released into the environment. Examples include scalpels, needles, syringes, broken glass, microscopic slides, and tubes.
4. Medical waste, known by a variety of names, all of which have the same basic description, i.e. the type of waste that is infected or possibly contaminated by infectious material and is generated throughout the health-care procedure.

All of them alluded to the waste generated by medical procedures in health-care facilities, research centres, and laboratories. It also includes the same types of waste that come from minor and dispersed sources, such as garbage produced during in-home health-care (such as self-administration of insulin, home dialysis, and recuperative care). Although the phrases are sometimes interchanged, there is a difference between ordinary HCW and hazardous medical waste. The WHO classifies human tissue, fluids, sharps, and contaminated supplies as "biohazardous", while non-contaminated appliances and animal tissue are classified as "generic medical waste". Medical waste also includes office paper, general garbage, and cooking waste from health-care facilities, even though it is not regulated and is not harmful in nature.

There are also other definitions which include hospital waste, health-care waste, medical waste, biomedical waste, biohazardous waste, clinical waste, Regulated Medical Waste (RMW), and infectious medical waste. However, health-care waste (HCW) will be used in this chapter. There is a need for a uniform and internationally accepted definition of waste created in health-care amenities to get a better understanding of waste management in those facilities. World Health Organisation (WHO) [1] has defined these as detailed in Fig. 4.1.

4.3 Sources and Generation of HCW

4.3.1 Sources

There are guidelines that are applicable for HCW generated from health-care establishments, which can be grouped as follows (Table 4.1).

Fig. 4.1 Classification of HCW [1]

Table 4.1 Types of health-care establishments that generate waste

Large source	Medium source	Small source
• University hospitals and clinics	• Medical centres	• General medical practitioners
• Maternity hospitals and clinics	• Outpatient clinics	• Convalescent homes
• General hospitals	• Mortuary/autopsy facilities	• Nursing homes for the elderly
• District hospitals	• Farm and equine centres	• Medical consulting rooms
	• Hospices	• Dental practitioners
	• Medical laboratories	• Animal boarding
	• Medical research facilities	• Acupuncturist
	• Animal hospitals	• Veterinary practitioners and animal research
	• Blood banks and transfusion centres	• Pharmacies
	• Emergency services	• Cosmetic piercers
	• Obstetric and maternity clinics	• Mortuary and autopsy centres
	• Outpatient clinics	
	• Dialysis centres	
	• Military medical services	

Fig. 4.2 Category of HCW [1, 2]

According to WHO [1, 2], about 85% of the total waste created by health-care activities is ordinary, non-hazardous waste. The remaining 15% is classified as hazardous waste, as shown in Fig. 4.2.

Around the world, approximately 16 billion injections are given each year. Unfortunately, quite a significant amount of needles and syringes are not properly managed. Dioxins, furans, and particulate matter may be produced from open burning and improper incineration of medical waste. It is important to make sure that HCW is handled in a safe and environmentally sound manner so that it does not pose a risk to patients, health-care staff, and members of the general public, all of whom could be exposed to potentially harmful chemicals or microorganisms [2].

4.3.2 Generation of HCW

Several surveys have revealed the usual generation of HCWs. WHO [3] has reported statistics from various research works by different workers on the quantity of waste produced by health-care sources. Table 4.2 shows the data for Pakistan, Tanzania, and South Africa. Data for the United States of America is shown in Table 4.3.

Minoglou et al. [4] has summarised the HCW generation rates in selected countries based on various studies conducted in the world (Table 4.4). The waste generation rates by type of facility are further detailed in Table 4.5 [1]. Recent data of HCW generation rates are given in Fig. 4.3.

4.3.3 Compositions of HCW

WHO [5] has summarised from different sources various data on HCW compositions. These are shown in Tables 4.6, 4.7, 4.8, and 4.9. When establishing recycling programmes, it is critical to determine the material composition of general garbage.

Table 4.2 Different waste categories generated by health-care facilities in Pakistan, Tanzania, and South Africa [3]

Type of health-care facility	Total health-care waste generation	Infectious waste generation
Pakistan		
Hospitals	2.07 kg/bed/day (range: 1.28–3.47)	
Clinics and dispensaries	0.075 kg/patient-day	0.06 kg/patient-day
Basic health units	0.04 kg/patient-day	0.03 kg/patient-day
Consulting clinics	0.025 kg/patient-day	0.002 kg/patient-day
Nursing homes	0.3 kg/patient-day	
Maternity homes	4.1 kg/patient-day	2.9 kg/patient-day
Tanzania		
Hospitals	0.14 kg/patient-day	0.08 kg/patient-day
Health centres (urban)	0.01 kg/patient-day	0.007 kg/patient-day
Rural dispensaries	0.04 kg/patient-day	0.02 kg/patient-day
Urban dispensaries	0.02 kg/patient-day	0.01 kg/patient-day
South Africa		
National central hospital		1.24 kg/patient-bed/day
Provincial tertiary hospital		1.53 kg/patient-bed/day
Regional hospital		1.05 kg/patient-bed/day
District hospital		0.65 kg/patient-bed/day
Specialised hospital		0.17 kg/patient-bed/day
Public clinic		0.008 kg/patient-day
Public community health centre		0.024 kg/patient-day
Private day-surgery clinic		0.39 kg/patient-day
Private community health centre		0.07 kg/patient-day

Table 4.3 Total and infectious waste generation in a high-income country (United States of America), [3]

Type of health-care facility	Total health-care waste generation	Infectious waste generation
Metropolitan general hospitals	10.7 kg/occupied bed/day	2.79 kg/occupied bed/day
Rural general hospitals	6.40 kg/occupied bed/day	2.03 kg/occupied bed/day
Psychiatric and other hospitals	1.83 kg/occupied bed/day	0.043 kg/occupied bed/day
Nursing homes	0.90 kg/occupied bed/day	0.038 kg/occupied bed/day
Laboratories	7.7 kg/day	1.9 kg/day
Doctor's office (group practice, urban)	1.78 kg/physician-day	0.67 kg/physician-day
Doctor's office (individual, urban)	1.98 kg/physician-day	0.23 kg/physician-day

(continued)

Table 4.3 (continued)

Type of health-care facility	Total health-care waste generation	Infectious waste generation
Doctor's office (rural)	0.93 kg/physician-day	0.077 kg/physician-day
Dentist's office (group practice)	1.75 kg/dentist-day	0.13 kg/dentist-day
Dentist's office (individual)	1.10 kg/dentist-day	0.13 kg/dentist-day
Dentist's office (rural)	1.69 kg/dentist-day	0.13 kg/dentist-day
Veterinarian (group practice, metropolitan)	4.5 kg/veterinarian-day	0.66 kg/veterinarian-day
Veterinarian (individual, metropolitan)	0.65 kg/veterinarian-day	0.097 kg/veterinarian-day
Veterinarian (rural)	7.7 kg/veterinarian-day	1.9 kg/veterinarian-day

Table 4.4 Health-care waste generation rates (HCWGR) in selected countries [4]

	Country	HCWGR (kg/bed/day)	Country	HCWGR (kg/bed/day)
Africa	Algeria	0.96	Mauritius	0.44
	Cameroon	0.55	Morocco	0.53
	Egypt	1.03	Sudan	0.87
	Ethiopia	1.1	Tanzania	0.75
Asia	Bangladesh	1.24	Malaysia	1.9
	China	4.03	Pakistan	2.07
	India	1.55	Palestine	2.02
	Indonesia	0.75	Thailand	2.05
	Iran	3.04	Turkey	4.55
	Japan	2.15	Nepal	0.5
	Jordan	2.69	Lebanon	5.7
	Korea	2.4	Kazakhstan	5.34
	Laos	0.51	Vietnam	1.57
America	Argentina	3	Ecuador	2.09
	Brazil	2.94	El Salvador	1.85
	Canada	8.2	USA	8.4
Europe	Bulgaria	2	Netherlands	1.7
	Italy	4	Norway	3.9
	France	3.3	Spain	4.4
	Germany	3.6	Latvia	1.18
	Greece	3.6	UK	3.3

Table 4.5 The waste generation rates by type of facility. Adapted from [1]

Facility	Total HCW generation rate	Infectious HCW generation rate
Hospital	2 kg/bed-day	0.5 kg/bed-day
Clinic	0.02 kg/patient-day	0.007 kg/patient-day
Clinical laboratory	0.06 kg/test-day	0.02 kg/test-day
Maternity Centre	5 kg/patient-day	3 kg/patient-day
Basic Health Unit	0.04 kg/patient-day	0.01 kg/patient-day

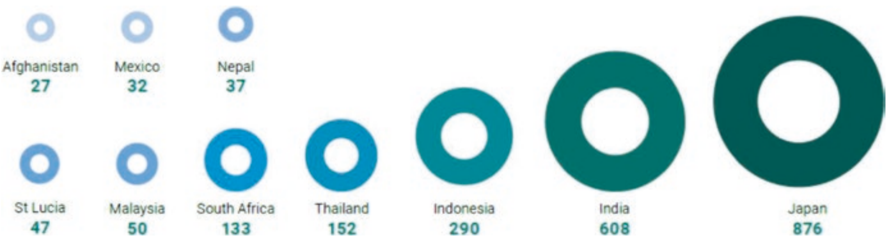

Fig. 4.3 HCW generation rates in selected countries (tonnes/day) [1]

Table 4.6 Bulk densities of HCW by components [5]

Canada		Ecuador	
Component	kg/m^3	Component	kg/m^3
Human anatomical	800–1200	General wastes	596
Plastics	80–2300	Kitchen wastes	322
Swabs, absorbents	80–1000	Yard wastes	126
Alcohol, disinfectants	800–1000	Paper/cardboard	65
Animal infected anatomical	50–1300	Plastic/rubber	85
Glass	2800–3600	Textiles	120
Bedding, shavings, paper, faecal matter	320–730	Sharps	429
Gauze, pads, swabs, garments, paper, cellulose	80–1000	Food wastes	580
Plastics, polyvinyl chloride (PVC), syringes	80–2300	Medicines	959
Sharps, needles	7200–8000		
Fluid, residuals	990–1010		

The heating value for incineration would be influenced by the moisture level of various components of overall HCW.

Hospital waste contains around 37% carbon, 18% oxygen, and 4.6% hydrogen, together with a variety of other components (Liberti et al. [6]). Mercury, lead, cadmium, chromium, arsenic, and zinc are among the hazardous elements contained in HCW and easily discharged during combustion (WHO [5]).

UNDP [7] has provided data on HCW waste in general. In most hospitals, the total waste created per bed per day is between 2 and 4 kg. Infectious waste created per bed per day in hospitals with effective separation is roughly 0.2–0.4 kg. Health-care waste has an average bulk density of 100–200 kg/m^3. In 2020, WHO [1] had revealed fresh data on the compositions of HCW (Table 4.10).

Table 4.7 Average composition of HCW WHO [5]

Jordan		Peru		Turkey		Taiwan (China)		Kuwait		Italy	
Component	%	Component	%	Component	%	Component	%	Component	%	Component	%
Paper	38	Mixed paper	22	Paper	16	Paper	34	Paper	24	Paper	34
		Cardboard	5	Cardboard	5			Cardboard	8		
Plastic	27	Plastic	12	Plastic	41	Plastic	26	Plastic	18	Plastic	46
Glass	10	Glass	8	Glass	7	Glass	7	Glass	10	Glass	8
Metals	5			Metal	2	Metal	4	Metal	9	Metal	0.4
				Food	17	Food	15	Food	12		
Textiles	11	Cotton/gauze	18	Textiles	10	Textiles	9	Textiles	11		
		Placenta	8							Anatomical	0.1
Garbage	9	Other	27	Other	3	Other	3	Other	8	Liquids	12

Table 4.8 Moisture content (%) of HCW components [5]

Overall HCW (%)					Infectious waste (%)	
Component	Ecuador	Component	Jordan	Turkey	Component	Canada
Paper/cardboard	16	Paper	22–57	4.5	Human anatomical	70–90
Food	45	Food		63	Plastics	0–1
Textile	30	Textile	37–68	8.6	Swabs, absorbents	0–30
Plastic/rubber	15	Plastic	11–54	2.8	Alcohol, disinfectants	0–0.2
Kitchen waste	47	Garbage	37–57		Animal infected anatomical	60–90
Garden Wastes	40	Carton		5	Glass	0
Medicines	64	Metal		2.25	Bedding, shavings, paper, faecal matter	10–50
		Glass		2.05	Gauze, pads, swabs, garments, paper, cellulose	0–30
		Other		8	Plastics, polyvinyl chloride, syringes	0–1
					Sharps, needles	0–1
					Fluid, residuals	80–100

Table 4.9 Heating value of health-care waste components. Adapted from WHO [5]

	Heating value (as fired)	
Component	MJ/kg	kcal/kg
Human anatomical	2–8.4	400–2000
Plastics	32–46	7700–11,000
Swabs, absorbents	13–28	3100–6700
Alcohol, disinfectants	25–32	6100–7800
Animal infected anatomical	2–15	500–3600
Glass	0	0
Bedding, shavings, paper, faecal matter	9–19	2200–4500
Gauze, pads, swabs, garments, paper, cellulose	13–28	3100–6700
Sharps, needles	0–0.1	0–30
Fluids, residuals	0–5	0–1100

Table 4.10 Common compositions of HCW [1]

	Composition of HCW (%)	
Name of the country/city	Hazardous	Non-hazardous
National level		
India	10–25	75–90
Kenya	15	85
Malaysia	20	80
Nepal	27	73
City level		
Dhaka city (Bangladesh)	18	82
Surabaya (Indonesia)	27	73
Pangkal Pinang (Indonesia)	10–30	70–90
Padang (Indonesia)	20	80

4.3.4 *Dangers and Risks of HCW*

HCW contains a significant amount of ordinary garbage and a small amount of hazardous waste. This section discusses the dangers of being exposed to hazardous (or risky) HCW. Health-care employees, trash workers, and the general public may be exposed to HCW if it is not properly regulated. For example, if needles are accidentally delivered to recycling facilities and their containers break open, they could pose a danger of infection. Housekeepers, housekeepers, janitors, and rubbish collectors are all at risk because sharps might protrude from plastic bags. Toxic waste contains bacteria, radioactive damage to the skin and respiratory system, poisoning, and environmental contamination. Our drinking water and the ecology could also be harmed by poorly discarded rubbish in landfills.

There are common health hazards known to be associated with HCW. These hazards can endanger the community in three modes: (1) as a result of accidental exposure to rubbish at municipal waste disposal facilities; (2) by exposure to chemical or biological pollutants in water, and (3) through exposure to chemical contaminants (e.g. mercury) from waste incineration.

4.3.4.1 Types of Hazards

Disease or harm can occur due to exposure to hazardous HCW. Figure 4.4 shows how the harmful nature of HCW may be linked to its features.

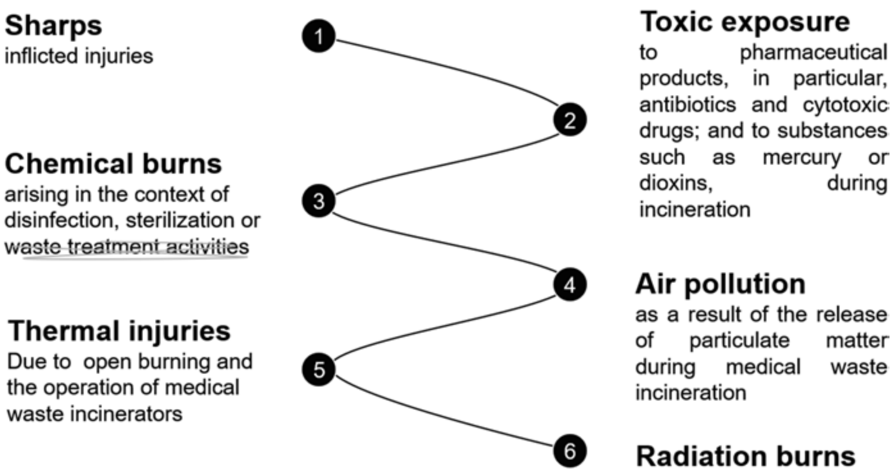

Fig. 4.4 The most common hazardous nature of HCW World Health Organisation [8]

4.3.4.2 Affected Individuals

Individuals who are exposed to hazardous HCW, as well as those who work in health-care facilities that produce hazardous waste and those who work outside of these facilities which are exposed to hazardous waste as a result of poor management, are all at risk. Figure 4.5 depicts the primary groups at risk.

The dangers of scattered, minor sources of HCW cannot be disregarded. Home HCW, such as dialysis waste and illicit drug use (usually intravenous) waste, are two examples of this type of waste.

4.3.4.3 Hazards by Infectious Waste and Sharps

A wide range of harmful bacteria can be found in infectious waste. Waste pathogens reach the human body in a variety of ways:

1. via a puncture, abrasion, or cut in the skin
2. via mucous membranes
3. via inhalation
4. via uptake

Sharps are classified as a particularly hazardous waste class because of the twofold risk of harm and disease transmission. Hypodermic needles are a major component of the sharps waste category, and they are particularly dangerous because they are frequently contaminated with blood from patients. Polluted sharps (especially

Fig. 4.5 The main risk group in HCW management

hypodermic needles) and concentrated pathogen cultures are among the waste products that pose the greatest danger to one's health. Sharps can cause more than just cuts and punctures; if they are tainted with microorganisms, they can also infect the wounds.

4.3.4.4 Pharmaceutical and Chemical Waste Hazards

Pharmaceutical wastes, like many substances, can be harmful. They can be highly flammable, caustic, or explosive. A health-care facility's pharmaceutical waste might come from a variety of activities and places. Expiring, underused, and possibly tainted pharmaceuticals, such as vaccinations and biological materials used for therapy, gloves, masks, and bottles, are all included in this type of garbage. Pharmaceutical waste presents a unique treatment and management problem. Large volumes held at pharmacies, distribution facilities, hospitals, and other locations must be controlled to minimise the risk of leakage or public exposure. As well as being harmful to patients and the environment, certain drugs are genotoxic (cause cancer in humans) or mutagenic (damage genetic material). Carcinogenic and/or teratogenic waste is produced by medical facilities that treat cancer.

Many chemicals and medications used in health-care are dangerous (WHO [5]). They are typically discovered in small amounts in HCW, but larger amounts can be detected when undesired or outmoded chemicals and medications are discarded. Chemical wastes can cause intoxication through acute or chronic exposure, as well as physical damage such as chemical burns, which are the most prevalent. Intoxication can occur when a chemical or medicine is absorbed through the skin or mucous membranes or when it is inhaled or consumed. Skin, eyes, and mucous membranes of the airways may be damaged by flammable or caustic chemicals that come into contact with the skin, eyes, or airways (e.g. formaldehyde and other volatile substances). Laboratory workers, particularly in speciality and research hospitals, are exposed to dozens of chemicals on a daily basis.

The hazardous qualities that are most important to HCW, as listed by WHO in 2014 [5]. The following is included:

- Toxic. At some amount of exposure, most substances are hazardous. Toxic fumes, dust, and vapours are especially dangerous because they can be breathed and swiftly move from the lungs into the bloodstream, allowing for fast circulation throughout the body.
- Corrosive. Strong acids and alkali bases can erode other materials, which include clothing, totally. They can inflict significant chemical burns and irreversible harm if splashed on the skin or eyes. Some of them also decompose into deadly gases, making them much more dangerous.
- Explosive. When exposed to heat or flame, some materials, such as volatile liquids, are ignited in small spaces, and the uncontrolled release of pressurised gases can explode.

- Flammable. Some compounds can easily cause a fire in a substance. Burn quickly, spread quickly, and emit a lot of heat. Solvents, fuels, and lubricants are among the flammable compounds kept in laboratories, medical areas, and workshops.
- Reactive chemically. Proper containers should be used when handling these compounds. When exposed to air or water, some can burn, while others can burn when mixed with other chemicals. It is worth noting that reactive materials can burn without being exposed to heat or flames. Any time they come into contact with air, they have the potential to spontaneously catch fire and release hazardous fumes.

4.3.4.5 Genotoxic Waste Hazards

Because it can cause mutation, teratogenicity, or carcinogenesis, genotoxic waste is particularly hazardous. It raises serious questions about patient safety, both during treatment and afterwards, and as a result, it should be handled with utmost caution. Genotoxic waste includes the following: cytostatic drugs, vomit, urine, or faeces from people who have undergone cytostatic treatment, chemicals, and radioactive substances.

The main compounds in this category, cytotoxic (or antineoplastic) medicines, have the power to destroy or inhibit the growth of specific living cells and are employed in cancer chemotherapy. They are crucial in the treatment of a variety of cancers, but they also have a wide range of applications as immunosuppressive drugs in organ transplantation and the treatment of a variety of disorders with an immunological base. In oncology and radiotherapy units, cytotoxic drugs are most widely used; however, their usage in other medical departments is increasing, and they may also be used outside of the hospital setting. The most commonly used genotoxic substances in medical practice are (1) chemicals (benzene), (2) radioactive materials, and (3) other cytotoxic and other drugs (azathioprine, chlorambucil and chlornaphazine, cyclosporin, cyclophosphamide and semustine, tamoxifen, thiotepa, treosulfan).

Many antineoplastic medications have been proven to be carcinogenic and mutagenic in animal tests, and secondary neoplasia (developing after primary cancer has been eliminated) has been linked to some types of chemotherapy (WHO [5]).

Many cytotoxic medications are extremely irritating and can cause serious local side effects when they come into contact with the skin or eyes (Table 4.11). Dizziness, nausea, headaches, and rashes are all possible side effects of cytotoxic medicines. Any release of genotoxic waste into the environment has the potential to be terrible for the environment.

Table 4.11 Category and types of cytotoxic drugs (WHO [5])

Category	Types
Alkylating agents	Vesicant (blistering) drugs: aclarubicin, chlormethine, cisplatin, mitomycin
	Irritant drugs: carmustine, cyclophosphamide, dacarbazine, ifosfamide, melphalan, streptozocin, thiotepa
Intercalating agents	Vesicant drugs: amsacrine, dactinomycin, daunorubicin, doxorubicin, epirubicin, pirarubicin, zorubicin
	Irritant drugs: mitoxantrone
Vinca alkaloids and derivatives	Vesicant drugs: vinblastine, vincristine, vindesine, vinorelbine
Epipodophyllotoxins	Irritant drugs: teniposide

4.3.4.6 Radioactive Waste Hazards

The category of illness caused by radioactive waste is determined by the type and extent of exposure to the radioactive material. Everything from dizziness and vomiting to more serious problems might be caused by it. When exposed to high levels of radiation, radioactive waste has the potential to damage genetic material. Handling highly active sources, such as those found in diagnostic tools (e.g. gallium sealed sources), can result in far more serious injuries, including tissue loss and the need for amputation of body parts. Extreme situations may result in death. Contamination of the external surfaces of containers, as well as the wrong mode or length of waste storage, might pose risks to low-activity radioactive waste. The most vulnerable are health-care employees, as well as workers of waste handling and cleaning who are exposed to radiation.

Radioactive materials are used in both diagnostic and therapeutic processes in health-care facilities. The majority of radiation therapy is normally done in a hospital's nuclear medicine department. Radioactive waste includes medical equipment contaminated with trace amounts of specific isotopes, clothing, biological material (pathological waste), and the radiation source itself (e.g. a cobalt block). Body parts and fluids can become radioactive when radioactive elements are injected into human bodies, such as iodine to treat a damaged thyroid gland or iridium pellets to eliminate prostate cancers. The urine and faeces of the patient may include pathological radioactive waste. By infusing radioactive antigens into the bloodstream, radioimmunoassay is a frequently used technique for determining the amounts of chemicals inside the body. Radioactive wastes could include packaging materials, cleaning fluids, and paper wipes.

Fortunately, some of the radioactive elements used in the human body have very short half-lives. Fast-decaying isotopes are chosen partially to reduce negative effects and to ensure that residual radiation does not harm healthy tissue. As a result, isotope containing waste tends to lose its radioactivity rapidly, lowering the dangers of storage and disposal. Every situation and utilisation of radioactive substances, on the other hand, must be assessed to establish the optimum storage and disposal strategy.

It takes half the atoms of each radioactive isotope to decay into a different isotope for each isotope to have its own unique half-life. One half-life produces another half-life, which can be radioactive or stable (non-radioactive), depending on the type of isotope decaying. Half-lives might be as short as a few seconds or as long as tens of millions of years.

Alpha, beta, and gamma radiation are all forms of radiation (this is oversimplified). Humans and animals can be contaminated by any of them. Using a piece of cardboard to separate the radioactive material from people is all that is needed to halt alpha and beta particles. The higher, stronger gamma rays are capable of penetrating solid materials like concrete. It is now possible to estimate the radiation dangers posed by various materials and devise protective measures.

Radiation exposure can produce headaches and nausea in the case of light exposure, as well as more significant symptoms (anaemia, skin rashes, and tissue damage) in the case of excessive exposure. Even radioactive materials employed in diagnostic tools (such as gallium) can be dangerous if they escape. Long-term exposure to radiation (if the substance remains entrenched in the body) can result in cancer and birth abnormalities in children.

Specialists can estimate how radiation levels will change over time by knowing a material's composition. The dangers caused by radioactive waste, unlike normal hazardous waste, diminish over time.

Iodine 125 has a half-life of about 60 days. Thyroid cancer patients are given iodine 131, which has an 8-day half-life and is used to destroy cancerous thyroid cells. When other isotopes are used for imaging, beta radiation is preferred since it emits the most energy.

4.4 Reduce, Reuse, and Recycling (3R's) of HCW

4.4.1 The Waste-Management Hierarchy

For public health reasons, there is a range of ways to deal with waste management. Waste hierarchy can be used as a framework for summarising the various approaches. The most desirable is at the top, while the least desirable is at the bottom (Fig. 4.6). "Desirability" is defined as the sum of the environmental, public health, financial affordability, and social acceptability implications of each method.

"Reduce, Reuse, and Recycle" (the "3Rs" concept), which broadly refers to resource sustainability, is at the heart of the waste management hierarchy's "3Rs" philosophy. It is best practice to avoid or recover as much as possible from waste at or around a health-care institution rather than burying it. It is sometimes referred to as addressing waste "at the source" rather than "end-of-pipe" solutions. Avoiding waste production as much as possible is the most optimal method if it is possible to do so. It is preferable if waste may be used for secondary purposes when possible. To decrease the health and environmental implications of waste that cannot be retrieved, the least preferred choices, such as treatment or land disposal, must still be needed.

Fig. 4.6 The waste management hierarchy

4.4.2 Waste Reduction

Over time, working with medical experts should be the goal of long-term waste reduction in the medical field (or minimisation). Waste minimisation is often employed to reduce waste at the point of generation, but health-care administrators can also reduce waste generation by modifying their purchasing and stock-control strategies. All staff should be trained in waste minimisation because they have a responsibility to discharge in this strategy. This is especially critical for employees in departments that produce substantial amounts of toxic HCW. Chemical and pharmaceutical manufacturers can play a bigger role in waste-reduction efforts. The health centre should promote this by procuring exclusively from vendors who can fulfil small orders quickly, accept returns of unopened items, and provide hazardous waste disposal services outside.

The following are some examples of policies and practices that are common to reduce waste volumes through reduction at source:

- Procurement cuts: choosing more environmentally friendly supplies and may be utilised in lesser quantities or that cause less hazardous waste.
- Physical cleaning procedures are preferred over chemical cleaning methods (e.g. steam disinfection instead of chemical disinfection).
- Product wastage can be avoided (e.g. in nursing and cleaning activities). At the hospital level, management and control procedures are in place.
- Hazardous chemical purchases are centralised.

- The use of hazardous waste chemicals in the health centre is tracked from delivery through disposal. Chemical and pharmaceutical product inventory management may also need to be implemented.
- Rather than purchasing large quantities all at once, smaller amounts should be purchased more frequently (applicable in particular to unstable products).
- A product's oldest batch should be utilised first.
- Each container's contents are fully utilised.
- Tracking the expiration dates of all items at the time of arrival and refusing to accept things from a supplier that are out of date.

4.4.3 Green Procurement

Decreased waste toxicity is also good for the environment because it makes the process of treating and disposing of it easier. A buying manager at a health-care facility, for example, could look into purchasing plastics that are easily recyclable or ordering supplies that are delivered without extra packaging.

Polypropylene, polyethylene, and polyethylene terephthalate are the most simply recyclable plastics worldwide (PET). Polyvinyl chloride (PVC), on the other hand, is the most difficult to work with, mainly because its products exist in a range of forms with various additions. Mixed-material packaging, like card or paper coated in plastic or aluminium foil, is almost never recyclable. Because of the toxicity of certain additives, PVC should be avoided wherever feasible. Bisphenol A, which is an endocrine disruptor, is also used to make polycarbonate. PVC gloves are most commonly replaced with latex or nitrile gloves. PVC tubing, polyethylene IV bags, and ethylene vinyl acetate bags for saline and blood can all be replaced by latex or silicone tubing, polyethylene IV bags, and ethylene vinyl acetate bags. Although ethylene oxide is applied to sterilise medical instruments, it is carcinogenic, and its use is highly not recommended wherever possible.

4.4.4 Reduce, Recycle, and Reuse

4.4.4.1 Recycling Symbols for Plastics

There is a worldwide categorisation system for plastics. The following are examples of common categories in health-care settings (Fig. 4.7):

Four types of polyethylene are typically used in health-care: low-density (LDPE) (4); high-density (HDPE) (5); and polypropylene (PP) or PETE (1).

Understanding the seven plastic codes will make selecting plastics and determining which plastics to recycle much easier. Water bottles with a three or a five on them, for example, cannot be recycled in most US counties. A three denotes that the water bottle is made of polyvinyl chloride, while a five indicates that it is

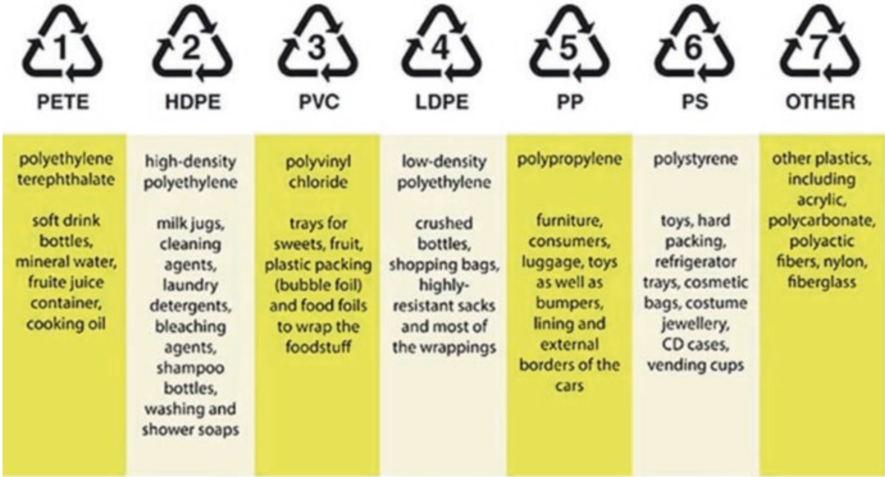

Fig. 4.7 Plastic recycling codes

constructed of polypropylene, both of which are not recognised by most public recycling centres.

4.4.4.2 Safe Reuse

Not all materials in a health-care facility can be reused, with single-use (medical) gadgets being of special concern. In general, non-disposable materials should be used for medical operations when their reuse after being washed has been proved to reduce infectious to acceptable levels. It is not acceptable to reuse single-use devices due to the unacceptable risk of cross-infection they pose.

4.4.4.3 Reuse and Recycling

Among the organisations that recycle include municipalities, commercial enterprises, homes, and public institutions like schools and hospitals. Recycling waste goods into new products and composting organic waste materials to make compost or soil conditioner for agricultural or other uses are two examples of waste recovery. “Recovery” could also apply to energy recovery, which involves converting trash into fuel for electricity generation or direct heating. On-site incinerators may be an attractive and cost-effective solution for heating hospitals, public buildings, and residential areas.

Recycling is becoming more frequent in several health-care facilities, especially for the large, non-hazardous portion of waste. Reduced disposal fees or having a recycling firm pay for waste that is recovered can reduce costs dramatically. There will be recyclable materials in some of the hazardous infectious wastes (such as cardboard, paper, packaging, tubing, etc.). The pathogens in these products can be eliminated by cleaning and adhering to safe handling guidelines.

Hospital food waste composting is also growing increasingly common, particularly in countries where landfill use is becoming more restricted due to regulation, taxes, service fees, or land constraints. But if you manage your compost properly, you can reduce the risk of attracting rodents and other pests.

In order to move current practices up the waste-minimisation hierarchy from mostly disposal to recycling or even prevention, all health-care facilities' waste-management strategies should contain the waste-minimisation hierarchy. Opportunities to reduce the amount of materials used and waste generated will be obvious at many points during the project life cycle. Educating health-care workers on how to use medical supplies responsibly is another simple option that may be implemented. It's possible to reduce waste by reusing items, but this option has its own set of challenges. As a result of the risk of infection transmission to patients and personnel, it is necessary to identify which reuse techniques are safe and which should be avoided.

In order to reduce waste, it's critical to implement life cycle management strategies for commonly used products and services. Another option is to work with suppliers to produce things made from materials that decay more quickly or maybe repurposed for secondary purposes. It is possible to reduce both physical waste and environmental impact by combining these developments in HCW waste treatment and disposal.

From an environmental, economic, and social standpoint, the waste-management hierarchy offers unambiguous recommendations on which waste-management options are most desired. These procedures should be employed if they are feasible. Minimisation is always better than generating garbage and then dealing with, treating, and disposing of it. A health-care facility should make recycling and waste reduction a part of its regular routine. All personnel should engage in waste-minimisation techniques on a daily basis to promote staff, patient, and public safety.

4.4.5 Segregation, Storage, and Transport of HCW

WHO [5] has listed concepts of waste segregation, storage, and in relation to managing the waste from its generation to disposal. Each medical area should have a separate container for each type of segregated waste; each container should be tagged when it is full so that supervisors can keep track of waste generation. It is important to classify medical waste into several categories depending on their possible hazards and disposal routes, and separate containers should be provided in each medical area to hold each of these categories of medical waste, according to the person who generates it.

As a general rule, hazardous and non-hazardous wastes should not be mixed during collection, transport, or storage; collected waste is frequently transported to a central location for treatment and disposal; staff should be aware of the risks associated with the wastes they are handling, as well as the proper disposal procedures.

The waste generator should segregate as close to the place of generation as possible. The administration of the health-care facility is responsible for ensuring that sufficient segregation, transportation, and storage system is in place, as well as that all employees follow the proper protocols. Hazardous waste should be kept separate from non-hazardous garbage. Typically, hazardous waste is divided into two categories: used sharps and potentially infectious materials. Bandages, tubing, swabs, disposable medical items, and tissues are the most common components in the latter.

Separate containers are used to separate common, non-hazardous garbage, potentially infectious waste, and used sharps. Other types of containers can be used for different sorts of trash, such as chemical and pharmaceutical wastes, or to segregate pathological waste from the rest of the waste flow, where it must be managed and disposed of differently.

A colour-coding method for trash containers is sometimes mandated by national law in a large number of nations (see, for example, Table 4.12) [9]. When waste is labelled with different colours, the potential danger that it poses can be seen more clearly.

Each region's waste containers are labelled to identify the source, track the types and quantities of waste produced in each region, and trace waste segregation concerns back to a medical area. Labelling each container with the medical area's details, the day and time it was closed, as well as a person's name is a simple

Table 4.12 Disposal method recommended by the World Health Organization [9]

Waste categories	Colour of container and markings	Type of container	Collection frequency
Infectious waste	Yellow with biohazard symbol (highly infectious waste should be additionally marked HIGHLY INFECTIOUS)	Leak-proof strong plastic bag placed in a container (bags for highly infectious waste should be capable of being autoclaved)	When three-quarters filled or at least once a day
Sharp waste	Yellow, marked SHARPS with biohazard symbol	Puncture-proof container	When filled to the line of three-quarters
Pathological waste	Yellow with biohazard symbol	Leak-proof strong plastic bag placed in a container	When three-quarters filled or at least once a day
Chemical and pharmaceutical waste	Brown labelled with appropriate hazard symbol	Plastic or rigid container	On-demand
Radioactive waste	Labelled with a radiation symbol	Lead box	On-demand
General HCW	Black	Plastic bag inside a container which is disinfected after use	When three-quarters filled or at least once a day

Fig. 4.8 Comparison of common hazardous waste symbols

approach to keep track of what's in it. Each waste container should have an international hazard emblem attached to it. Figure 4.8 illustrates a number of symbols that are relevant to the many sorts of hazardous waste that are generated in a health-care facility.

4.4.6 Collection Within the Health-Care Facility

WHO [5] also described the frequency of collection, which depends on the amount of waste generated in each section of health-care facility. Separate collection systems and collection time are normally practised for general waste, infectious or other hazardous wastes. Daily collection is normally implemented.

Ready for pickup, waste bags should be sealed. At each garbage collection point, replacement bags or containers should be accessible so that full ones may be replaced right away. Waste bags and containers should be tagged with the date, type of waste, and location of generation in order to keep track of waste from generation to disposal. It is a good idea to keep track of the waste's weight.

As part of the daily routine in a medical facility, infectious waste may be collected during the day to prevent dirty bandages from lingering in the medical facility longer than necessary. Visitors that arrive later in the day will produce more general waste, such as newspapers and food wrappers; thus, it is advisable to collect general and recyclable debris after visiting hours has finished. An operating room generates a huge volume of potentially infectious waste; therefore, it may be necessary to have many collections a day to accommodate the operation's schedule.

4.4.7 On-Site Transport of Waste

WHO [5] has recommended that for the safety of patients and staff and to limit the number of heavy carts going through patient care areas, on-site transportation can take place at times when there are fewer people around. It is preferable to build a health-care facility with distinct floors, stairways, or elevators for waste transport and other ancillary amenities. All transportation workers should wear personal protective equipment (PPE), such as gloves and robust and closed shoes, as well as overalls and face masks. Trash should be transported in separate containers for hazardous and non-hazardous waste. It is necessary to provide trolleys that are suitable for the situation. Garbage, especially hazardous waste, should never be transported by hand due to the possibility of infection or injury from infectious material or incorrectly disposed sharps that may protrude from a container. In the event of breakdowns or maintenance, spare trolleys should be accessible. Cleaning and disinfecting the cars should be done on a daily basis. All waste bag seals must be in place and intact at the end of the transport [5].

In general, WHO [5] distinguishes three modes of transportation:

1. General waste transportation trolleys shall be painted black, used only for non-hazardous trash, and conspicuously labelled "General waste" or "Non-hazardous waste".
2. Infectious waste and used sharps trash can be carried together. To avoid the transmission of infectious agents, infectious waste should not be carried alongside other hazardous trash. Trolleys should be labelled with an "Infectious garbage" sign and coloured in the appropriate infectious waste colour code (yellow).
3. Other hazardous waste, such as chemical and pharmaceutical waste, must be transported separately in boxes to central storage facilities. Waste chutes should not be used in health-care institutions because they increase the danger of transferring airborne illnesses.

4.4.8 *Off-Site Transport of Waste*

The transportation of health-care trash out from a health-care facility on public streets is known as off-site transport. If hazardous health-care waste is sent across an international border for treatment, it must adhere to national rules as well as international accords. UN recommendations on the transportation of hazardous goods can be relied upon in the absence of national laws by the appropriate authorities (UN [10]). There should be sufficient training for drivers of vehicles hauling hazardous health-care waste. They must also be medically fit to operate a motor vehicle. To reduce the possibility of accidents and spillages, a designated vehicle should be employed, identified to identify its load, and its payload secured. Vehicles or containers used to transport medical waste should not be utilised to transport anything else.

4.5 Treatment and Disposal Methods of HCW

Treatment is needed to reduce the risk of HCW causing harm while conserving the environment; there needs to be a waste-management hierarchy, in which first steps are done to decrease waste and reuse it whenever possible before any other activities are taken. Unusable waste materials should be treated to reduce their volume and any health or environmental risks before being transferred for safe final disposal if this isn't possible. WHO [5] compiled information from a variety of sources on the common practice of disposing of medical waste in various parts of the world (Table 4.13).

There are a number of factors to consider, including the waste characteristics, technology capabilities and requirements, environmental and safety issues, and costs, which all vary depending on the geographical conditions in which they are implemented. All must be considered when selecting a treatment system. Sharps, pathogenic, and pathological waste are among the hazardous components of medical waste. They can be treated by various means which will be discussed in the subsequent sections. The majority of HCW produced has the potential to be contagious. One of the most well-established methods of waste management relies on the

Table 4.13 Disposal practices for medical waste in many countries throughout the world

Country	Disposal methods
Mongolia	Open dumping or open burning, incineration, autoclaving
Bangladesh	Dumping
Libya	Dumping, incineration
Greece	Recycling-reuse, pyrolytic combustion, landfill
Malaysia	Landfill, incineration, recycling
India	Landfill, incineration, autoclaving, recycling-reuse

Source: WHO [5]

disinfection method. Disease transmission can be reduced or even prevented through the practice of "disinfection", which involves reducing or removing pathogenic germs (pathogens). WHO [5] has described various treatment options of HCW. These are discussed here.

4.5.1 Incineration

4.5.1.1 Category

Incineration is a thermal treatment of waste. Heat (thermal energy) is used in these procedures to kill pathogens in the waste. This procedure is the controlled burning of waste at high temperatures. Incineration is a dry oxidation method that turns organic and combustible trash into inorganic, non-combustible stuff, reducing waste volume and weight significantly. They are representative of the majority of treatment centres in operation around the world. On-site burning has the benefit of being a quick and easy disposal technique; however, there are issues about emissions. Modern incineration has been designed to comply with the stringent limit of air emissions. There are various types of heat treatments; the most common are incinerators, pyrolysis, and gasification. The difference is mainly based on the burning temperature and the working pressure.

The temperature at which the fire burns vary depending on the type; normally, temperatures range from around 200 °C to over 1000 °C. Organic material can be destroyed in a variety of ways, including combustion, pyrolysis, and gasification. Another drawback of these technologies is the emission of combustion byproducts into the atmosphere, which produces residual ash, and the need to dispose of it. Steam, carbon dioxide, nitrogen oxides, and a wide range of volatile compounds are the primary byproducts of HCW combustion (e.g. metals, halogenic acids, incomplete combustion products), and particulate matter, as well as solid leftovers such as ashes. A typical schematic of the incineration technology is shown in Fig. 4.9.

Substoichiometric air levels are used in pyrolysis and gasification processes. Table 4.14 explains the differences between pyrolysis, gasification, and incineration. Table 4.15 compares the advantages and disadvantages of the incineration process. This is followed by Table 4.16, which details the number of incinerators for HCW management in selected countries.

4.5.1.2 Required Waste Characteristics

The basic and desirable characteristics recommended for incineration with energy recovery include (Patil [13]):

- Nett heating/calorific (value) above 1200 kcal/kg (5021 kJ/kg)
- Organic/volatile matter above 40%

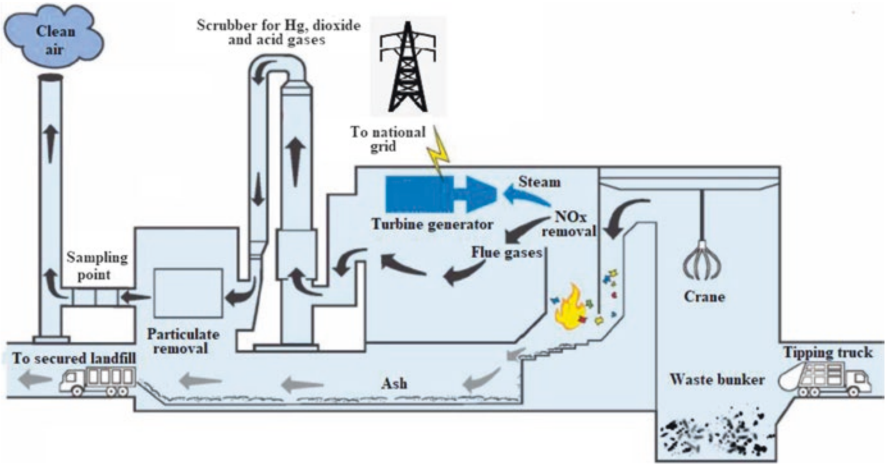

Fig. 4.9 A typical type of incinerator with energy recovery [11]

Table 4.14 Typical pyrolysis, gasification, and incineration reaction conditions [12]

	Pyrolysis	Gasification	Incineration
Reaction temperature (°C)	250–700	500–1600	800–1450
Pressure (bar)	1	1–45	1
Atmosphere	Inert/nitrogen	Gasification agent: O_2, H_2O	Air
Stochiometric ratio	0	<1	>1
Product from the process			
• Gas phase	H_2, CO, C_xH_y, H_2O, N_2	H_2, CO, CO_2, CH_4	CO_2, H_2O, O_2
• Solid phase	Ash, coke	H_2O, N_2	NO_2
• Liquid phase	Pyrolysis oil, water	Slag, ash	Slag, ash

Table 4.15 Advantages and disadvantages in applying the incineration technology. Source WHO [1]

Advantages	Disadvantages
• Significant reduction of waste volume and weight	• High energy requirement
• Ensure decontamination (combustion at minimum 800 °C temperature)	• The combustion of HCW produces mainly gaseous emissions, including steam, CO_2
• No post-treatment is needed for final disposal	• NO_x, a range of volatile substances (e.g. metals, halogenic acids, products of incomplete combustion)
	• Potential emissions of carcinogens
	• Particulate matter, plus solid residues in the form of ashes, which are to be treated as toxic

Table 4.16 Number of incinerators for HCW management in selected countries [1]

Country	Number of incinerators
Bangladesh	• 5 incinerators are installed, of which three are operating
India	• 225 incinerators installed
Indonesia	• Out of 646 hospitals dedicated to handling COVID-19 patients, 20 have their own licenced incinerators.
	• In general, there are 110 licenced incinerators in regular hospitals, located mainly in urban areas. nine incinerators, mostly damaged, with only one licenced in Bangka Belitung. two incinerators, with no licence from the Ministry of Environment and Forestry in Pangkal Pinang
Kenya	• 10 diesel operating incinerators located in high volume health-care facilities
Malaysia	• 12 incinerators for hazardous waste
Mexico	• 19 incinerators installed with capacity enough to handle 117,519 tonnes/year
Saint Lucia	• 20 small-scale pyrolysis units purchased but not installed and commissioned
South Africa	• 9 incinerators
Thailand	• 15 incinerators for infectious waste in the country
	• 62 hospitals operate their own incinerators
	• 1 incinerator at Mae Fah Luang University in Chiang Rai

Table 4.17 Key properties of HCW [1]

Parameter	Average value
Moisture content	15% by weight
Energy value (heating)	15 MJ/kg (3600 kcal/kg or 6400 BTU/lb)
Combustion residues	15% by weight
Bulk density	100–200 kg/m^3

- Content of non-combustible fines (inerts) below 15%
- Moisture content below 45%
- Fixed carbon below 15%

There are, however, minor differences in the values. According to WHO [5], incineration of garbage is only affordable and possible if the waste's "heating" (or "calorific") value is at least 2000 kcal/kg (8370 kJ/kg). While hospital wastes with high quantities of plastics can have calorific values above 4000 kcal/kg (16,740 kJ/kg), HCW can include a significant proportion of wet waste and have substantially lower calorific values. However, according to WHO [1], a greater calorific value is required for combustion (Table 4.17) [1].

Energy recovery appears to be an appealing option because many current bigger incineration facilities can reuse the heat generated by waste burning. However, this is only feasible for larger or regionally located incinerators.

4.5.1.3 Types of Incinerators for HCW

Incinerators can be as simple as a basic combustion unit or as complicated as high-temperature operational plants. All types of incinerators should be able to eliminate microorganisms from waste and reduce waste to a negligible amount of ash if handled appropriately. It is important to balance the public health benefits of removing pathogens against the technical requirements necessary to minimise the pollution in the air or groundwater from waste combustion byproducts (WHO [5]).

HCW are normally treated with one of three incineration technologies:

1. A dual-chamber starved-air incinerator, which is designed to burn infectious HCW and operates in the starved-air mode (below stoichiometric conditions) in the primary chamber
2. Multiple hearth/chamber incinerators, such as in-line incinerators and retort incinerators used for pathological waste
3. Rotary incinerators

4.5.1.3.1 Incinerators with a Lack of Oxygen

HCW is usually incinerated using a method known as starved-air incineration. Incineration processes include controlled-air incineration, pyrolysis, two-stage incineration, and static hearth incineration. Incineration air has a lower stoichiometric composition than that of the combustion process (that is, the amount of oxygen is less than the ideal proportion needed for burning carbon and hydrogen).

This type of incinerator has a primary chamber and an additional post-combustion chamber (Fig. 4.10). Ashes and gases are produced as a result of the rubbish being thermally burned in the first chamber utilising an oxygen-deficient, medium-temperature combustion process (800–900 °C). To start the process, a fuel burner is inserted into a primary chamber. There is a wide range of waste residence time, ranging from 1 h up to 4 h, depending on the installation. High temperatures (between 1100 and 1600 °C) and an abundance of air are used to burn the primary chamber's gases in the secondary chamber, reducing smoke, carbon monoxide, and odours. Any temperature below 1100 °C (the European Union's Waste incineration directive 2000/76/EC) requires additional energy to be delivered by a gas or fuel burner. Larger pyrolytic incinerators (more than 20 tonnes/day capacity) are normally intended to run continuously. They can also operate automatically, including garbage loading, ash disposal, and internal movement of burning waste.

4.5.1.3.2 Multiple Chamber/Hearth Incinerators

Pathological waste is still incinerated in several countries using multiple hearths incinerators, which were once more common. There are two primary types of incinerators: in-line and retort. Volatile organic compounds from the flue gas are

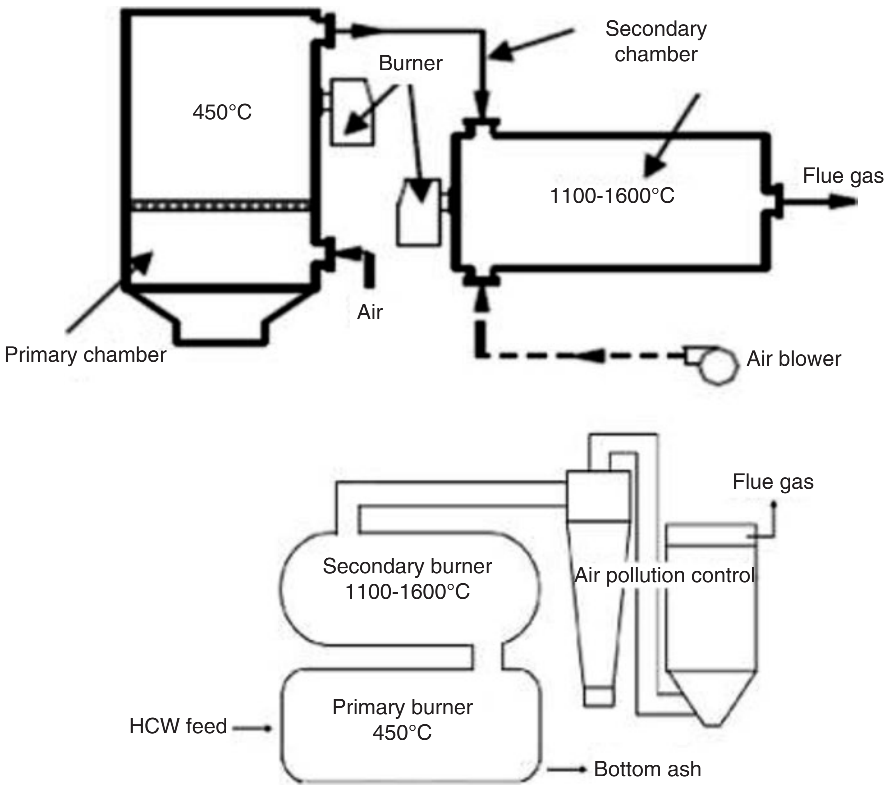

Fig. 4.10 A typical dual-chamber starved-air incinerators [5]

combusted in a secondary incinerator, and the gas is then forced to turn in different directions to remove particle matter as ash residue. The incinerators are rectangular in shape.

4.5.1.3.3 Energy-Recovering Rotary Kilns

An oven and post-combustion chamber are the two components that make up the rotary kiln [5]. As a large-scale central/regional HCW incinerator, they can also be constructed to burn chemical wastes. The proper temperatures and scrubbing equipment (used to clean the flue gas) are employed in a modern design rotary kiln.

The axis of a rotating kiln is tilted away from the horizontal (3–5% slope). Two to 5 rpm of rubbish are charged into the kiln's upper end. The ashes are then released from the bottom of the pyre. In the post-combustion chamber, the kiln-generated gases are heated to high temperatures to burn off gaseous organic components, and their residence time is typically 2 or more seconds. These machines can function at full capacity for long periods of time, and they can handle a variety of loading

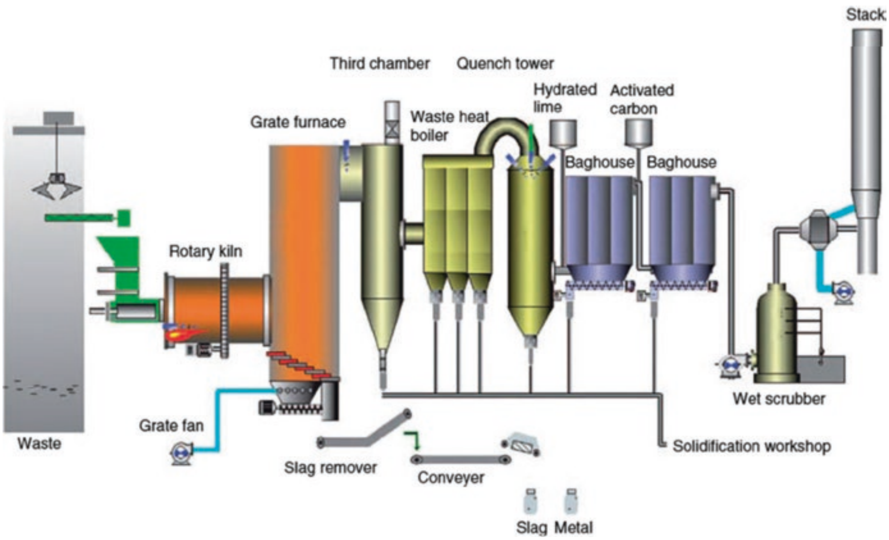

Fig. 4.11 A typical rotary-kiln incinerator [14]. (Reprinted from Jiang, X., Li, Y., Yan, J. Hazardous waste incineration in a rotary kiln: a review, Waste Disposal & Sustainable Energy, (2019) 1: 3–37 https://doi.org/10.1007/s42768-019-00001-3 with permission from Springer)

methods. Specialised trash disposal firms and industrial areas away from health-care facilities are appropriate for toxic waste treatment facilities.

Rotary kilns are normally operated at temperature ranges between 900 and 1200 °C. Its capacity of up to 10 tonnes/h is available. Its operating costs are high; however, it can be compensated with an energy recovery facility. The system also requires well-trained personnel. A typical rotary-kiln incinerator is shown in Fig. 4.11.

4.5.1.4 Environmental Control of Incinerators

In those countries that have joined the Stockholm Convention, incinerator discharges should meet national criteria and follow the Stockholm Convention's BAT, and best environmental practices (BEP) advice. If no such regulations have been developed by the competent authorities, the BAT/BEP guidelines or international standards may be used as reference (Table 4.18) (WHO [5]).

It is possible to treat flue gases with a combination of wet, dry, or semi-dry flue gas treatment processes. It is essential to keep the combustion temperature under control and to rapidly cool the exhaust gases in order to prevent dioxins and furans from reforming.

WHO [5] describes several MCW incineration specifications and operation protocols. The Stockholm Convention is a legally binding pact aimed at preventing persistent organic pollutants from harming human health and the

Table 4.18 Emission guidelines for HCW incinerators [5]

Pollutant	Unit	Standard condition	US EPA emission limits			EU emission limits			AP 42
			Small	Medium	Large	Daily ave.	Half-hour ave.	0.5–8-h ave.	
Particulate matter of total dust	mg/m^3	20 °C, 101.3 kPa, 7% O_2, dry	66	22	18				223
		273 K, 101.3 kPa, 11% O_2, dry				10	10, 30		
Carbon monoxide	ppm (v)	20 °C, 101.3 kPa, 7% O_2, dry	20	1.8	11				127
	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry				50	100		
Dioxin/furans	ng TEQ/m^3	20 °C, 101.3 kPa, 7% O_2, dry	0.0013	0.014	0.035				4.1
	ng TEQ/m^3	273 K, 101.3 kPa, 11% O_2, dry						0.1	
Gaseous and vaporous organics as total organic carbon	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry				10	10, 20		15
Hydrogen chloride	ppm (v)	20 °C, 101.3 kPa, 7% O_2, dry	15	7.7	5.1				1106
	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry				10	10, 60		
Hydrogen fluoride	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry				1	2, 4		
Sulphur dioxide	ppm (v)	20 °C, 101.3 kPa, 7% O_2, dry	1.4	1.4	8.1				54.6
	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry							
Nitrogen oxides	ppm (v)	20 °C, 101.3 kPa, 7% O_2, dry	67	67	140				93
	mg/m^3	273 K, 101.3 kPa, 11% O_2, dry				200	200,400		

environment. In order to comply with the agreement, countries that are signatories must employ the greatest possible technology for new incinerators. The limits for best available technology and best environmental practices established by the Stockholm Convention limit dioxin and furan levels in air emissions to 0.1 ng I-TEQ/Nm^3 at 11% O_2. Furthermore, dioxin levels in treatment plant wastewater from any gas treatment scrubber effluents should be considerably below 0.1 ng I-TEQ/L.

The Stockholm Convention specifies primary and secondary measures for achieving dioxin and furan elimination performance levels. The following are the primary indicators:

- Only operate the combustion chamber at temperatures below 850 °C.
- Start-up and shut-down operations are handled by auxiliary burners.
- It is advised that the incinerator be run continuously.
- The oxygen supply should be continuously adjusted based on consistency of the input material's heating value.
- Secondary air or recirculated flue gas, preheating the air-streams, or regulating the air inflow, high turbulence of exhaust gases, and reduction of excess air should be maintained after the last injection of air, or at 1100 °C for wastes containing more than 1% halogenated organic compounds (usually found in healthcare waste) and 6% O_2 by volume.
- The incinerator's operation and management should be able to be monitored online from a central console, including temperature, oxygen content, carbon monoxide, and dust levels.

The secondary reduction of dioxins and furans involves a combination of dust-removal equipment and additional procedures such as catalytic oxidation, gas quenching, and wet or semi-dry adsorption systems. Fly and bottom ash, as well as wastewater, must be dealt with carefully. It is recommended that all of these parameters be checked on a regular basis in accordance with national regulations and manufacturer recommendations. These include carbon monoxide concentrations in the flue gas as well as oxygen concentrations therein, particulate matter, hydrogen chloride, sulphur dioxide, nitrogen oxides, and hydrogen fluoride.

4.5.2 Low Heat Treatment Systems

This type of non-incineration heat treatment is divided into four stages: thermal, chemical, irradiative, and biological. The bulk of non-incineration technologies employ thermal and chemical processes. The primary purpose of the treatment method is to eliminate bacteria from the waste stream. Facilities should ensure that the disinfection technique is in compliance with state regulations. Various low heat treatment systems are discussed here [5].

4.5.2.1 Heat Processes

This type of thermal technique uses elevated temperatures to kill microorganisms, but not so high that the waste will burn or pyrolyze. Thermal low-heat technologies generally operate between 100 and 180 °C. In both wet and dry circumstances, low-heat reactions can occur. Moist (or wet) thermal treatment, in which steam is used to disinfect waste, is a common practice in autoclaves and other steam-based treatment systems. Because moist heat (hot water and steam) generated by microwave energy is used to disinfect, microwave treatment is primarily a moist thermal process. Rather than using water or steam, hot air is employed in dry-heat activities.

In dry-heat systems, waste is heated using infrared or resistance heaters by conduction, irradiation, convection, and/or thermal radiation.

4.5.2.2 Chemical Processes

Various chemical disinfectants such as chlorine, dissolved chlorine dioxide, bleach (sodium hypochlorite), peracetic acid (lime solution), ozone gas, or dry inorganic compounds are utilised in this process (e.g. calcium oxide powder). A typical cleaning method in hospitals, chemical disinfection, is now being utilised to treat health-care workers. Waste is disinfected rather than sterilised when chemicals are used to kill or inactivate microorganisms. Liquid waste from hospitals, such as blood, urine, faeces, or sewage, is best treated with chemical disinfection methods. However, they can still be employed in the remediation of solid wastes. Microorganisms, pollution, disinfectant concentration and quantity, as well as contact time and mixing requirements, are all factors that must be taken into account when it comes to optimal utilisation of wastes.

Shredding, grinding, and mixing are typically required in chemical processes to maximise the waste's exposure to the chemical agent. Grinding ensures that the chemical agent is exposed to all areas of the waste and facilitates the disposal of any residues. In liquid systems, the disinfectant may be removed and recycled by passing the waste through a dewatering portion. In addition to chemical disinfectants, encapsulating chemicals can solidify sharps, blood, or other bodily fluids in a solid matrix before disposal. Another example of a chemical process is the use of heated stainless-steel tanks to break down tissues, pathological debris, anatomical components, and animal corpses using hot alkali.

4.5.2.3 Irradiation Technologies

Electron beams, cobalt-60, and ultraviolet irradiation are all examples of irradiation treatments. Gamma radiation, emitted by cobalt, kills all the germs in waste. The expensive cost of cobalt and the high operating costs have hindered commercial ventures from utilising this technology for the treatment and management of medical waste. Controversy has also arisen over the method of cleaning the substance using radiation. As with autoclaving and microwave methods, it is not recommended for pathological wastes.

To avoid increased occupational exposures to electromagnetic radiation, these devices require shielding. The amount of waste material absorbed by pathogens determines the effectiveness of pathogen killing. Waste bags and containers can be pierced by electron beams. It is possible to use germicidal ultraviolet radiation as a supplement to conventional disinfection methods; however, it cannot penetrate tight garbage bags.

4.5.2.4 Biological Processes

These processes can be found in natural living creatures; however, when used for HCW treatment, they pertain to the decomposition of organic materials. To speed up the degradation of pathogen-containing organic waste, certain biological treatment systems employ enzymes. Composting and vermiculture (worm-assisted digestion of organic waste) are biological methods that have been effectively employed to decompose hospital food garbage, together with other organic digestible waste and placenta waste [15]. Another biological process is the spontaneous breakdown of pathological waste by burial.

4.5.2.5 Mechanical Processes

Shredding, grinding, mixing, and compaction technologies are examples of mechanical treatment techniques that reduce waste volume but do not remove pathogens. Mechanical techniques are rarely used as stand-alone HCW treatment methods but rather as a supplement to other treatment methods. Mechanical destruction, which can be employed to disintegrate needles and syringes, can render trash unidentifiable (depending on the type of shredding). In thermal or chemical treatment methods, mechanical devices such as shredders and mixers can increase the pace of heat transfer or expose a larger surface area of garbage to waste treatment. The level of management and maintenance needed to treat HCW safely and effectively increases dramatically when mechanical devices are employed to prepare wastes before other types of waste annihilation. After disinfecting the incoming HCW waste, shredders, mixers, and other mechanical devices should be used.

4.5.2.6 Steam Treatment Technologies

WHO [5] has detailed autoclave and microwave technology for HCW treatment. These are discussed as follows.

4.5.2.6.1 Autoclaves

Autoclaves are used to disinfect and sterilise items in a physical manner. Medical autoclaves have been used for over a century to sterilise medical items. They've also lately been adopted for the treatment of infectious waste. They use a combination of steam, pressure, and time to accomplish their goals. Autoclaves kill bacteria and spores by using high temperatures and pressure. They're utilised to sterilise media, tools, and labware as well as decontaminate biological waste. Before being disposed of, medical waste that may contain bacteria, viruses, or other biological material should be autoclaved to kill any bacteria, viruses, or other biological material.

The most often used alternative to incineration is autoclaving, also known as steam sterilisation. It is a low-heat thermal process that uses steam to disinfect waste by putting it into direct contact with it for a predetermined period of time. It is both less expensive and has no known health risks. Prior to disposal in a landfill, wastes are sterilised or disinfected using this process. In hospitals, autoclaves are typically used to sterilise reusable medical equipment. Waste from patient care (such as gauze, bandages, and gowns) can be sterilised in an autoclave, including cultures and stocks, sharps, objects contaminated with blood, and limited amounts of fluids and laboratory rubbish (excluding chemical waste). They are, however, commonly applied for small amounts of waste, particularly highly infectious waste like sharps and microbial cultures. About 90% of regulated medical wastes, particularly microbiological wastes, can be autoclaved. Cytotoxic, pathological, or other toxic chemical wastes, on the other hand, are not suited for autoclaving. In general, autoclave sterilisation achieves a 99.99999% inactivation of pathogens.

High-pressure metal containers are used in autoclaves, which have sealed doors and pipelines for steam to enter and exit. Autoclaves are used to sterilise food, medicine, and other items. An important factor in the effectiveness of steam treatment is air's ability to act as an insulator. To enable heat penetration into the waste, air must be removed from the autoclave. To avoid the emission of pathogenic aerosols, waste treatment autoclaves must treat the air that is withdrawn at the start of the operation, unlike instrument sterilisation autoclaves. This is commonly accomplished by steaming the air or putting it through an air filter before releasing it.

Pressure pulse, gravity-displacement, and pre-vacuum autoclaves are the most common types of autoclaves used for HCW treatment. Autoclaves for waste treatment can be as small as 20 L and as large as 20,000 L. Low-heat thermal processes emit far fewer pollutants into the atmosphere than high-heat thermal processes. In a gravity-displacement autoclave, steam is injected into the chamber under pressure, driving the air downwards into the chamber's outlet port. Before injecting steam, a pre-vacuum (also known as high-vacuum) autoclave uses a vacuum pump and/or a steam ejector to remove air from the chamber. It is more effective, but it is also more expensive. Because this procedure is more efficient at eliminating air and disinfecting waste, it takes less time to disinfect. A simplified concept of a pre-vacuum autoclave is shown in Fig. 4.12.

In a pressure pulse autoclave, pressure pulsing is utilised to eliminate the air. Gravity, vacuum pulsing, and pressure-vacuum are the three main types of pressure

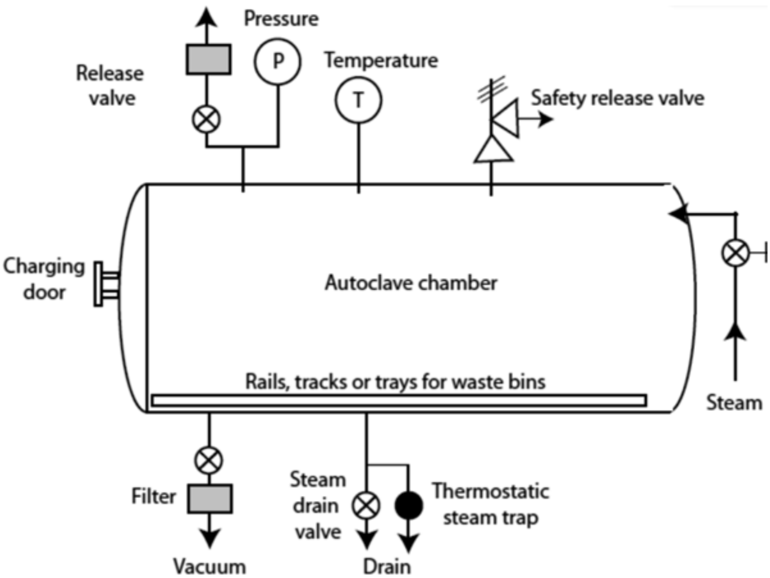

Fig. 4.12 Simplified schematic of a pre-vacuum autoclave. (WHO [5])

pulsing systems. After a predetermined level of pressure has been attained, pressure gravity (also known as steam flushing) is used to release steam and bring the pressure back up to a predetermined level. It is comparable to a high-vacuum method, except that it uses two or more vacuum cycles at the beginning of the therapy. During therapy, the pressure is increased, and the vacuum is released multiple times, which is how pressure-vacuum systems work. Steam penetration is accelerated by using alternating pressure cycles. Pressure vacuum systems, in general, have the quickest time to achieve high disinfection standards.

When using an autoclave for disinfection, make sure you have the right combination of temperature/pressure and time in there. One to 2 bar (approximately 15–30 psi, or 1540–2280 mmHg absolute) gauge pressure is required for waste treatment autoclaves. Previously, while using saturated steam, a 30-min maximum exposure time limit was established at 121 °C. This translates to a minimum pressure of 205 kPa (2.05 bar) (15 psi). Psi-pound per square inch is an abbreviation in the list of abbreviations. The load's composition and volume may necessitate a longer cycle time.

Temperature and pressure, process sequence, load size and stacking configuration and packing density; types and integrity of bags or containers used; waste materials (such as bulk density, heat capacity and thermal conductivity), the amount of residual air, and the moisture content of the waste [16] influence the performance of an autoclave system. When sterilising liquids, such as blood or urine bags, the sterilisation technique and time must be altered.

Autoclave trash retains its physical appearance. After treatment, the garbage may be rendered unrecognisable using a mechanical technique such as shredding or

Table 4.19 The advantages and disadvantages in the autoclave technology [1]

Advantages	Disadvantages
• Suitable for soiled wastes, bedding and personal, protective equipment, clinical laboratory waste, reusable instruments, waste sharps, and glassware	• Cannot treat volatile and semi-volatile organic compounds, chemotherapeutic waste, mercury, other hazardous chemical and radiological waste, large and bulky bedding material, large animal carcasses, sealed heat-resistant containers
• Low-heat thermal processes produce significantly less air pollution emissions than high-heat thermal processes	• Odours can be a problem around autoclaves if there is insufficient ventilation
• No specific pollutant emissions limits for autoclaves and other steam treatment systems	• Poorly segregated waste may emit low levels of alcohols, phenols, formaldehyde, and other organic compounds into the air
• Waste does not require further processing; it can be disposed of on a municipal landfill as it is disinfected and not hazardous anymore. However, some countries request to render the waste unrecognisable, then it is shredded afterwards, but this depends on the legal regulation	• Treated waste from an autoclave retains its physical appearance
• Available in various sizes from lab autoclaves to large autoclaves used in large waste treatment facilities	• Waste requires further processing for final disposal

Source: [1]

grinding. Shredding can reduce the volume of treated waste by 60–80%; however, it has a high failure rate.

For almost a century, autoclaves have been used to sterilise medical instruments, and they have only lately been used for the treatment of infectious waste. An autoclave consists of a metal container built to resist high pressures, a sealed door, and a set of pipes and valves that allow steam to enter and escape the container. The advantages and disadvantages of autoclave technology are listed in Table 4.19 [1].

4.5.2.6.2 Microwave Treatment Technologies

Patients are often treated with moist heat and steam generated by microwave energy in the majority of microwave-based treatments. With a frequency of 2450 MHz and a wavelength of 12.24 cm, microwave energy quickly heats water in the waste [1].

Sterilising garbage with microwaves is another application for this cutting-edge technology. Patients are often treated with moist heat and steam generated by microwave energy in the majority of microwave-based treatments. The thermal activity of electromagnetic radiation energy with a frequency range ranging from 300 to 300,000 MHz rapidly heats the water in the trash. Microwaves at a frequency of 2450 MHz and a wavelength of 12.24 cm kill the majority of microorganisms. Intermolecular heating is a type of microwave heating. To neutralise any biologicals

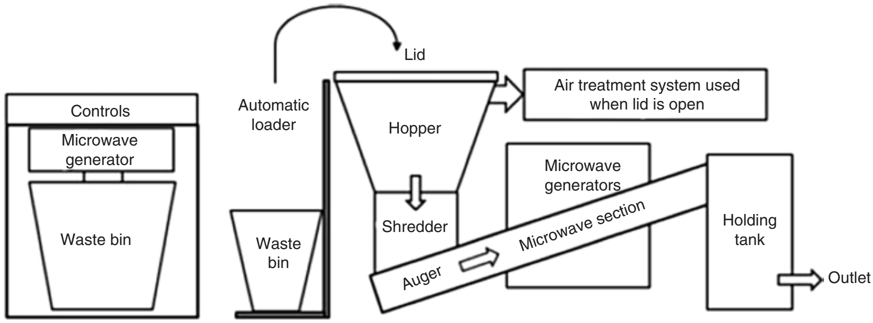

Fig. 4.13 A schematic diagram of a batch and semi-continuous microwave system. (WHO [5])

present, garbage is shredded first, then mixed with water and heated within. Pathogenic components are eliminated via heat conduction when microwaves instantly heat the water enclosed within the waves. This procedure, which is comparable to autoclaving, can manage approximately 90% of medical wastes. According to reports, shredding reduces volume and uses less energy than an incinerator.

A microwave generator delivers microwave energy into a treatment area or chamber in most microwave treatment systems (magnetron). Two to six magnetrons, each with an output of roughly 1.2 kW, are commonly utilised in batch or semi-continuous processes. Batch systems have a capacity of 30–100 L, making them ideal for large-scale waste management. Depending on the therapist, a session might take anywhere from 30 min to an hour.

Automated charging, hopper, shredder, conveyor screw, and steam generator are some of the components of a typical semi-continuous microwaving system (Fig. 4.13). Waste bags are put into the hopper, which may be steam sprayed. The air is evacuated by a filter as the waste bags are loaded, preventing the spread of airborne germs. Once the hopper cover is closed, the waste is shredded. Before being heated to 100 °C by four or six microwave generators, waste particles are transported by an auger (conveyor screw). It is possible to shorten the exposure time by using a holding segment. A secondary shredder may be used if treated sharps require finer shredding. A semi-continuous microwave system on a big scale can treat roughly 250 kg of food every hour (3000 tonnes/year).

Some common waste categories include cultures and stocks, sharps and things contaminated with blood or body fluid, isolation/operation/lab trash (excluding chemical waste), and soft waste (e.g. gauze, bandages, gowns, and bedding) from patient care that are commonly treated in microwave systems. Non-volatile organic chemicals, chemotherapeutic waste, mercury, other hazardous waste and radioactive materials should not be treated with microwaves. It is possible to prevent the release of aerosols during the feed process by using a fully enclosed microwave unit equipped with an effective filter. The advantages and disadvantages of microwave technology are given in Table 4.20 [1].

Table 4.20 The advantages and disadvantages of microwave technology [1]

Advantages	Disadvantages
• Suitable for soiled wastes, bedding and personal, protective equipment, clinical laboratory waste, reusable instruments, waste sharps and glassware	• Volatile and semi-volatile organic compounds, chemotherapeutic waste, mercury, other hazardous chemical waste and radiological waste should not be treated in a microwave
• A fully enclosed microwave unit can be installed in an open area and used with a HEPA filter to prevent the release of aerosols during the feed process	• Treated waste from an autoclave microwave unit retains its physical appearance
• Odour is somewhat reduced, except in the immediate vicinity of the microwave unit	• Waste requires further processing for final disposal
• A large-scale, semi-continuous microwave unit is capable of treating about 250 kg/h (3000 tonnes/year)	• Very limited volume reduction, no weight reduction
• Waste does not require further processing. It can be disposed of on a municipal landfill as it is disinfected and not hazardous anymore. However, some countries request to render the waste unrecognisable, then it is shredded afterwards, but this depends on the legal requirement	
• Available in various sizes from lab autoclaves to large autoclaves used in large waste treatment facilities	

4.5.3 Encapsulation and Solidification

As detailed in [5], untreated HCW should not be disposed of in municipal landfills. The HCW should confine the waste before it is disposed of if there is no other option. Examples of encapsulation include filling containers with waste and adding an immobilising chemical before sealing them. Sharps, chemicals, or pharmaceutical residues are collected in either high-density polyethylene cubic boxes or iron drums. The containers or boxes are then filled with a medium such as plastic foam, bituminous sand, cement mortar, or clay material. On drying, the containers are sealed and disposed of in landfills.

To use this method, you must have access to encapsulating materials that can be used to dispose of sharps and chemical or medicinal leftovers. Encapsulation alone is not recommended for non-sharps waste, although it can be used in conjunction with other treatment methods. Scavengers are less likely to be able to get their hands on HCW waste if the procedure is used. To use this method, you must have access to encapsulating materials that can be used to dispose of sharps and chemical or medicinal leftovers. Encapsulation alone is not recommended for non-sharps waste, although it can be used in conjunction with other treatment methods. Scavengers are less likely to be able to get their hands on HCW waste if the procedure is used.

Solidification is the process of combining garbage with cement and other materials before disposal to reduce the possibility of harmful compounds in the waste transported into and polluted the surface or groundwater. It's especially good for pharmaceuticals and high-metal-content cremation ashes (the procedure is known as “stabilisation” in this case). The packaging should be removed, the medications crushed, and a mixture of water, lime, and cement added to solidify pharmaceutical waste. Onsite, a homogeneous mass is generated, and cubes (for example, 1 m^3) or pellets are manufactured. These can then be relocated to an appropriate storage location. Alternatively, the homogenous mixture can be carried to a landfill in a liquid form and put on top of previously landfilled municipal garbage before being topped with new municipal waste.

WHO [5] states that the average proportions (by weight) of the combination are 65% pharmaceutical waste, 15% lime, 15% cement, and 5% water. Cost-effective and easy-to-use mixing equipment are the main advantages of this method. Other than manpower, the essentials include a grinder or road roller to break up the stones, a concrete mixer, and a supply of cement, lime, and water.

4.5.4 Emerging Technologies

Because most current and emerging technologies do not have a track record in HCW applications, WHO [5] recommends that they be carefully examined before being adopted for routine use. Ozone, promession, and plasma pyrolysis are the most commonly discussed technologies in scientific literature. Using plasma arc torches or electrodes, plasma pyrolysis generates temperatures in excess of a million degrees Fahrenheit from electrical energy. In an atmosphere with little or no air, high temperatures are employed to pyrolyze waste. Another new method breaks down the pathogenic, toxic chemical, or pharmaceutical wastes with superheated steam at 500 °C. The vapours are then heated to 1500 °C in a steam reforming chamber. As with incineration, these processes are costly and require pollution control systems to remove impurities from exhaust gas before they can begin. Waste can be disinfected with ozone (O_3). Ozone gas is a powerful oxidant that degrades quickly into a more stable state (O_2). Shredders and mixers are necessary for ozone systems because they expose waste to the bactericidal agent. Uses for ozone include curing water and removing odours. Ozone can irritate the eyes, nose, and respiratory tract at quantities greater than 0.1 ppm. To ensure that the microbial inactivation criteria are met, regular testing should be performed, exactly like with other chemical treatment technologies.

Promession is a revolutionary technology for destroying anatomical waste that combines a mechanical process with heat removal. Human remains are disintegrated into powder utilising cryogenic freeze-drying with liquid nitrogen and mechanical shaking before being buried. The technique accelerates decomposition, reduces bulk and volume, and allows metal pieces to be recovered. Other emerging technologies include gas-phase chemical reduction, base-catalysed decomposition, supercritical water oxidation, sodium reduction, vitrification, superheated steam reforming, ozonation, biodegradation, mechanochemical treatment, sonic technology, electrochemical technologies, solvated electron technology, and phytotechnology [17, 18].

4.5.5 Gas Sterilisation

Heat-stable materials are employed in the majority of medical and surgical devices in health-care facilities, and steam is used to sterilise them. However, since the 1950s, there has been an increase in low-temperature sterilisable medical devices and tools (e.g. plastics). Gas sterilisation uses a sterilising chemical (such as ethylene oxide or formaldehyde) to treat medical waste that has been pumped into an evacuated, airtight chamber (WHO [4]). The gas will kill any hazardous or infectious agents that come into touch with the garbage.

Ethylene oxide gas has been used in heat and moisture-sensitive medical equipment since the 1950s. Medical devices can now be sterilised using a variety of low-temperature sterilisation methods (e.g. hydrogen peroxide gas plasma, immersion in peracetic acid, ozone, etc.). Sterilisation removes all germs from a product's surface or fluid to avoid disease transmission associated with its use [19]. The EPA does not recommend ethylene oxide for treating infectious wastes in countries like the United States because of its toxicity.

4.5.6 Land Disposal

After reduction or treatment, all waste systems will normally be sent to land for final disposal of the leftover HCW components. When a town or health-care facility does not have the means to treat trash prior to disposal, the direct use of a landfill is likely to be necessary. "Safe burial" will continue to be used for the disposal of HCW until adequate capacity for incineration, or other treatment options are available, particularly in many middle- and lower-income countries. At many medical facilities, hazardous waste (HCW) is accumulated and then burned or dispersed about the property. Even if the land disposal site is not established to the exacting standards utilised in higher-income areas, this poses a significantly greater risk of infection spread than regulated disposal in a landfill.

The ashes from the hazardous waste and HCW waste incineration facilities, as well as waste that is not suitable for burning, must be dumped in a secure landfill. A secured landfill is a specially designed region where waste goods are deposited. A secure landfill is often a hole in the earth; however, it can also be constructed above ground. A secured landfill's objective is to avoid any watery interaction between waste items and the natural environment. It is critical that groundwater does not generate runoff onto the surrounding environment. Hazardous and HCW waste is buried in safe landfills, while it is occasionally injected far underground in deep well injection systems.

The safe landfill, which was designed and built to the greatest of requirements, is used to dispose of both scheduled and hazardous garbage. For optimal safety, a minimum of two impermeable and chemically resistant liner systems are typically erected, with the facility itself resting on a strong geological barrier. Proper operation and maintenance of the landfill would ensure that this landfill pose no negative effects on the environment or on the people who work there. Heavy metals and other hazardous compounds are removed in the wastewater treatment facility after leachate from the secured landfill is pre-treated in a chemical treatment step.

4.6 HCW Management in Selected Countries

This section discusses HCW management in selected countries in Asia and Europe.

Medical waste is classified as B3 trash in Indonesia, according to Prasetiawan [20], and its management is governed by Government Regulation Number 101 of 2014 about the Management of Hazardous and Toxic Waste. The Minister of Environment and Forestry Regulation No. 56 the Year 2015 about Procedures and Technical Requirements for the Management of Hazardous and Toxic Waste from Health Care Facilities regulates the treatment of medical waste.

According to the Ministry of Environment and Forestry (KLHK), medical waste treatment facilities for health-care facilities in Indonesia have a capacity of 70.21 tonnes/day [20]. Furthermore, third-party processing services have a capacity of 244.08 tonnes/day (Soemiarno [21]). There are 2889 hospitals, 10,062 health centres (puskesmas), 7641 clinics, and other institutions like health laboratories, pharmacies, and blood transfusion units in total. Every day, Indonesia is expected to create 294.66 tonnes of medical waste (Nurali [22]). The government is attempting to expand the country's capacity for processing medical waste.

The government's efforts to close the gap in Covid-19 medical waste capacity should be commended. However, there are a few points that should be considered in light of this statement. Incinerators are still used in processing technology. Many elderly hospital incinerators in Indonesia, on the other hand, face a significant issue in achieving optimal combustion temperature (850–1200 °C). The lack of proper air pollution control continues to be a problem. Because of the possibility of mercury and dioxin emissions, some have been abandoned (Damanhuri [23]). The government has taken a number of steps to close the gap in medical waste treatment capacity, including optimising basic capacity and expanding reserve capacity such that total capacity reaches 877.26 tonnes/day, roughly three times reserve capacity. Medical waste management technology that isn't solely based on burning is also in the works.

Two hundred and ninety metric tonnes of medical waste are generated each day by Indonesia's 2820 hospitals and 9884 community health centres (Puskesmas), according to data from the Health Ministry, according to a report in the Jakarta Post [24]. Only 87 hospitals in Indonesia have on-site incinerators with a combined daily capacity of up to 60 tonnes, despite the fact that ten licenced medical waste processing plants have a combined daily capacity of 170 tonnes. The Environment and Forestry Ministry predicted that medical waste would rise as a result of the extensive use of protective gear and other single-use medical equipment during the pandemic. There is no evidence on how much medical waste was generated as a result of Covid-19. Medical waste generated by the 132 Covid-19 referral hospitals and the growing use of face masks and gloves by the general population is not to be overlooked.

India is a country where biomedical waste was handled and disposed of at a rate of 530 metric tonnes/day in India in 2018. This was only 20 metric tonnes fewer than the entire amount of rubbish produced that year. The most important phase in biological waste management is waste separation (Figs. 4.14 and 4.15). Some of the most usual places to find this waste are hospitals, private clinics, nursing homes as well as medical research institutes and funeral homes.

In China, in 2019 (Fig. 4.16), around 5600 metric tonnes of medical waste was produced in Shanghai in China. The 196 big and medium cities involved produced a total amount of around 843,000 of medical waste that year [26].

There are five categories of HCW in Malaysia: clinical waste (CW), radioactive waste (RW), chemical waste (CW), pressurised containers (PC), and general rubbish (GW) (Department of Environment [27]). CW is any waste that contains or has been in contact with any of the clinical waste types or that has been mixed with any of the clinical waste types, including human or animal tissue, blood or body fluids, excretions, drugs, pharmaceutical products, soiled swabs or dressings, syringes, needles, or sharps (Department of Environment [27]).

Malaysia's health ministry defines the following items as hazardous waste: (1) wastes containing human or animal tissue or blood or other body fluids, excretions, pharmaceutical drugs, or other items such as swabs or dressings, needles, or other sharp instruments; and (2) any other waste resulting from medical procedures. Table 4.21 provides the classification of HCW, which is designed for use in the health-care industry in Malaysia.

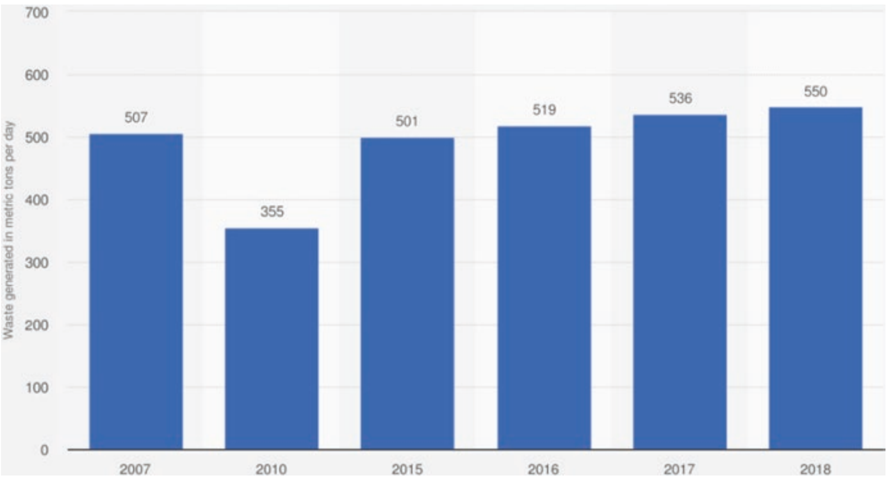

Fig. 4.14 Volume of biomedical waste generated in India from 2007 to 2018 (in metric tonnes per day) [25]

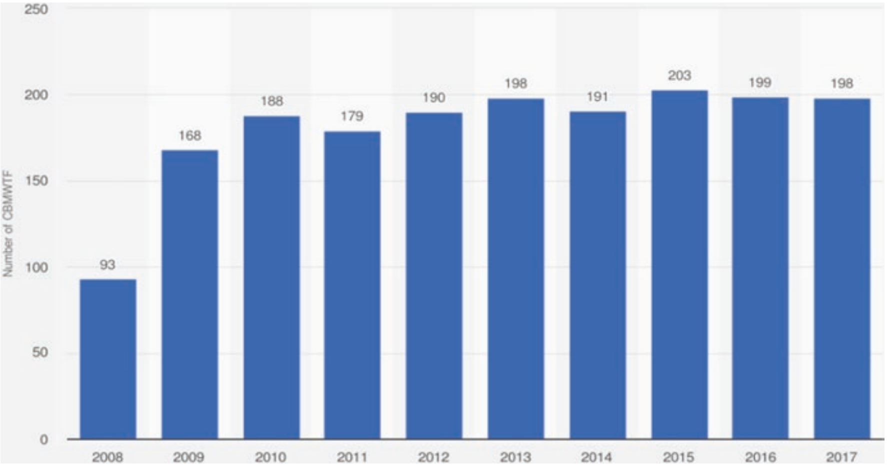

Fig. 4.15 Common biomedical waste treatment facilities (CBMWTF) in India from 2008 to 2017 [25]

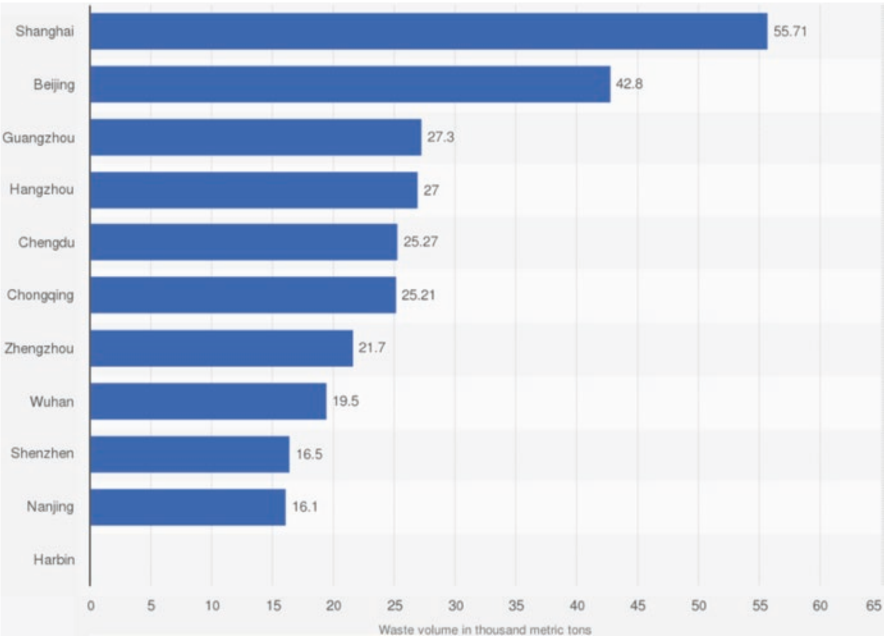

Fig. 4.16 Production volume of urban medical waste in China in 2019, by leading city (in 1000 metric tonnes) [26]

Table 4.21 Major clinical waste classifications and management recommendations in Malaysia [27]

Description	Waste management guidance
1. Blood and body fluid waste	
(a) Soiled surgical dressings, e.g. cotton wool, gloves, swabs. All contaminated waste from the treatment area. Plasters, bandages that have come into contact with blood or wounds, cloths and wiping materials used to clear up body fluids and spills of blood.	Special requirement on the management from the viewpoint of infection prevention. These categories of waste must always be incinerated completely in an appropriate incinerator.
(b) Material other than reusable linen, from cases of infectious diseases (e.g. human biopsy materials, blood, urine, stools).	
(c) Pathological waste, including all human tissues (whether infected or not), organs, limbs, body parts, placenta and human foetuses, animal carcasses and tissues, from laboratories and all related swabs and dressings.	
2. Waste posing a risk ("sharps")	
All objects and materials which are closely linked with health-care activities and pose a potential risk of injury and/or infection, e.g. needles, scalpel blades, blades and saws or any other instruments that could cause a cut or puncture.	Collected and managed separately from other waste. The collection container must be puncture resistant and leak-tight. This category of waste has to be disposed of/destroyed completely to prevent the potential risk of injury/infection.
3. Infectious wastes	
Clinical waste arising from laboratories (e.g. pathology, haematology, blood transfusion, microbiology, histology) and post-mortem rooms, other than waste included in category 1 waste.	Special requirement on the management from the view point of infection prevention. This category of waste must always be incinerated completely in an appropriate incinerator.
4. Pharmaceutical and cytotoxic pharmaceutical wastes	
(a) Pharmaceuticals which have become unusable for the following reasons:	
• Expiry date exceeded;	Class I—pharmaceuticals such as camomile tea, cough syrup, and the like which pose no hazard during collection, intermediate storage and waste management:
• Expiry date exceeded after the packaging has been opened or the ready-to-use preparation prepared by the user; or	Managed jointly with municipal wastes.
• Use is not possible for other reasons (e.g. call-back campaign).	Class II—pharmaceuticals that pose a potential hazard when used improperly by unauthorised persons:

(continued)

In Malaysia, the composition of health is mainly non-infectious waste (80%),

Table 4.21 (continued)

Description	Waste management guidance
ii.ii. (b) Wastes arising in the use, manufacture and preparation of, and in the oncological treatment of patients with, pharmaceuticals with a cytotoxic effect (mutagenic, carcinogenic, and teratogenic properties).	Managed in an appropriate waste disposal facility.
	Class III—Heavy metal containing unidentifiable pharmaceuticals: managed in an appropriate waste disposal facility.
	Intermediate storage of these wastes takes place under controlled and locked conditions. For reasons of occupational safety, cytotoxic pharmaceutical wastes must be collected separately from pharmaceutical waste and disposed of in a hazardous waste incineration plant.
5. Other infectious waste	
All health-care waste known or clinically assessed by a medical practitioner or veterinary/surgeon to have the potential of transmitting infectious agents to humans or animals. Used disposable bed-pan liners, urine containers, incontinence pads, and stoma bags.	Disposed of in a hazardous waste incineration plant licenced by the Department of Environment Malaysia.

Table 4.22 Composition of the HCW in Malaysia [28]

Type of waste	Composition
Non-infectious waste	80
Pathology waste	15
Sharps	1
Chemical and Pharmaceuticals waste	3
Other waste	1

followed by pathology waste (15%) (Table 4.22) [28].

To protect health-care professionals, waste collection employees, patients, and the general public, Malaysia has taken thorough steps to minimise practices by formulating and implementing suitable regulations and guidelines to integrate safety and health aspects in HCW. The Environmental Quality (Scheduled Wastes) Regulations 2005 [29], classify the HCW as a scheduled waste. These guidelines provide information on how to properly handle and manage health-care waste from hospitals and other health-care facilities (public and private). Under the regulations, different waste codes are employed, as detailed in subsequent sections.

The Malaysian government has opted to privatise a comprehensive HCW waste collection, transportation, and disposal system for all government hospitals because of the growing concern about the need for proper HCW management. Private health-care facilities must also ensure that their clinical wastes are properly

Table 4.23 Segregation of health-care solid waste in most hospitals in Malaysia

Category of waste	Example	Segregation
Non-clinical waste	Health-care waste that is not in contact with patient care and does not pose any hazard rather than recyclable waste such as discarded paper, plastic, etc.	Black colour plastic bag.
Infectious waste	Tissues, materials, or equipment that has been in contact with patient care.	Yellow colour plastic bag.
Sharp	Syringes, needles, scalpels, blades, cartridges, broken ampules, spike of drip set.	Sharp bin
Pharmaceutical	Time-expired drugs, used vaccine vial, drugs that have been spoilt or contaminated.	Yellow colour plastic bag.
Recyclable waste	Book, magazine, office paper, newspaper, plastic and tin, etc.—those are not contacted with patient care and do not pose any hazard.	Green colour plastic bag.

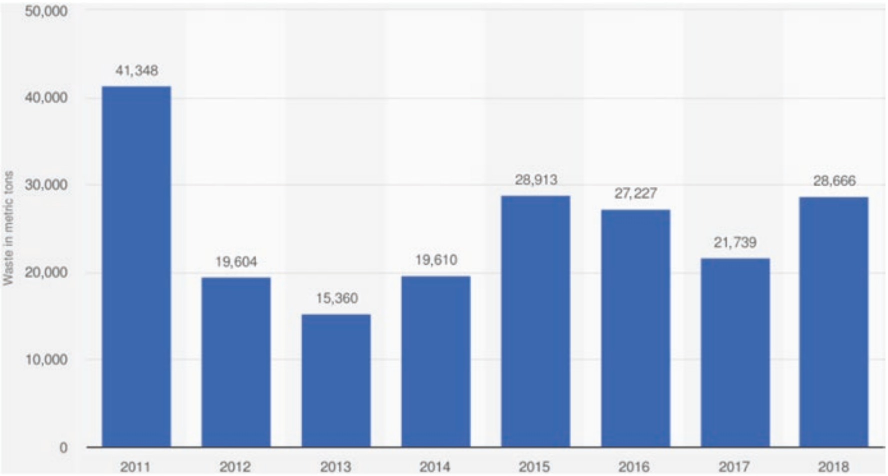

Fig. 4.17 Waste management in Spain from 2011 to 2018 for medical and biological waste (in metric tonnes) [30]

managed. Table 4.23 shows an example of how HCW wastes are segregated in most hospitals in Malaysia prior to the final disposal.

From 2011 to 2018, Fernández [30] reported the annual medical and biological waste processed in Spain in metric tonnes (Fig. 4.17). This particular form of garbage accounted for 28.7 thousand metric tonnes in total.

4.7 Legal Framework, Regulations, and Code of Practices of HCW Management

The correct segregation, storage, disposal, and documenting of waste are the core elements of HCW legislation. Through its colour-coding system, the authorised department in each country gives best practice standards for trash segregation and disposal. It is suggested that distinct waste streams be assigned different colours in order to make garbage management easier and more efficient. The colour code can be used from the time trash is generated until it is stored, transported, and disposed of.

Figure 4.18 [1] shows the global share of nations that have adopted HCW management laws as of 2020, broken down by region. Around 39% of Asian countries had passed specialised legislation on HCW management by 2020, making it one of the world's highest percentages. However, the same region had a similar proportion of countries with no HCW management plans in place. As of 2020, little more than half of the countries in the globe had some type of legislation addressing HCW management. This is especially important in light of the COVID-19 epidemic. Figure 4.19 depicts the common hierarchy of the regulatory and administrative framework for hospital waste management [5].

To see some of the examples, the legislations in the United Kingdom and Malaysia are discussed here. Their applications are generally not so much different as the case of other countries.

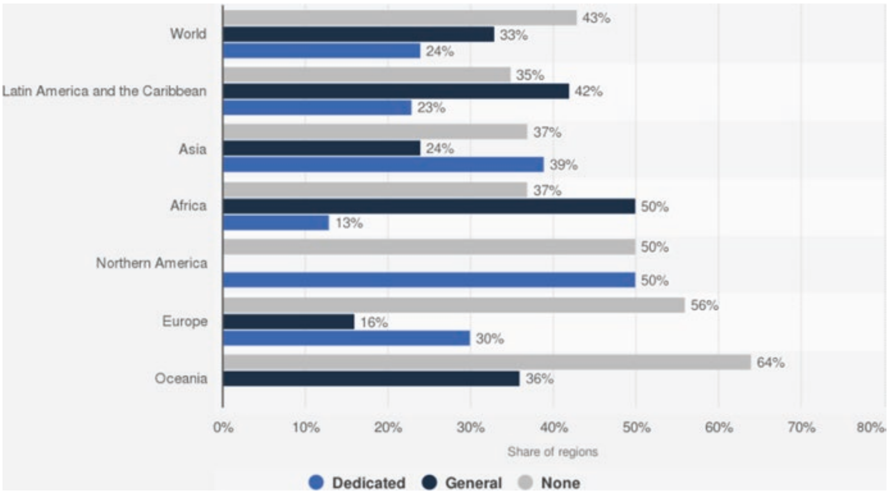

Fig. 4.18 Share of countries with adopted health-care waste (HCW) management legislation worldwide as of 2020 [1]

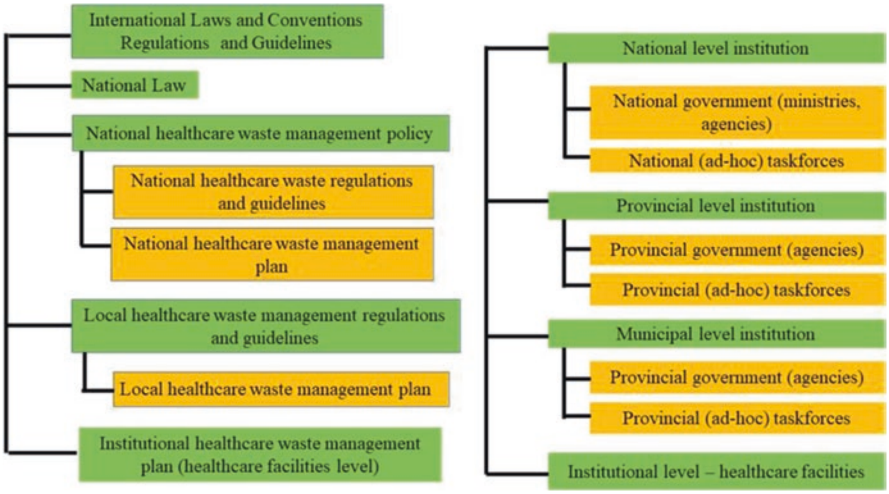

Fig. 4.19 The HCW management framework's common regulatory and institutional hierarchy [5]

4.7.1 United Kingdom

Over the years, the United Kingdom has enacted a number of regulations that address a variety of issues, including packaging and transportation, treatment, and staff health and safety. The following are the most important regulations that apply to HCW in the United Kingdom.

4.7.1.1 The 1990 Environmental Protection Act Was Enacted to Protect the Environment (Including Duty of Care Regulations)

This is the principal legislation controlling hospital waste management. Health-care providers have a Duty of Care to ensure proper waste management, which includes recording waste transfers and ensuring garbage is treated properly. It also necessitates adherence to the Waste Hierarchy. The Environmental Protection Act of 1990 was enacted as a piece of law. This legislation lays out strategies to manage trash in a way that prevents pollution of the land, water, and air. It imposes a duty of care on all businesses that produce or dispose of garbage, requiring them to do it in a safe manner. It also includes information on litter, public nuisances, and the regulation of certain substances.

4.7.1.2 The Hazardous Waste Directive (HazWaste Directive) of 2011

From trash creation through final recovery and disposal, this includes guidance on labelling, record-keeping, monitoring, and control duties. To protect the environment and human health, it prohibits the combination of hazardous substances and objects.

4.7.1.3 The Controlled Waste Regulations (England and Wales) 2012

Household, industrial, and commercial trash are classified as "regulated waste" and are governed by the Environmental Protection Act of 1990. This act was enacted in 2012 to designate specific waste types. Any industrial, commercial, or home waste is classified as controlled waste. As a result, they are governed under the Environmental Protection Act of 1990. Sewage and septic tank sludge are two examples of non-controlled waste.

4.7.1.4 Regulations for the Transportation of Dangerous Goods

These regulations apply to dangerous commodities transit by rail or road. According to them, all professionals handling hazardous waste must be ADR qualified and have the necessary knowledge to safely transport the trash. The Carriage of Dangerous Goods Regulations is another piece of regulation that influences HCW. This legislation examines the transportation of dangerous commodities and how to manage the risk of spills, which can result in dangerous risks. Health-care practitioners who transport clinical waste to be disposed of must adhere to these laws.

4.7.1.5 The Regulations on Statutory Duty of Care

These regulations establish guidelines for waste management that preserve the environment and human health. They apply to everyone who imports, produces, stores, or disposes of specific types of waste, such as clinical waste. Waste managers have a responsibility to guarantee that the waste they handle does not harm anyone or anything and is appropriately disposed of.

4.7.1.6 The Hazardous Waste Regulations of 2005 (Hazardous Waste Regulations)

In 2005, the Hazardous Waste Regulations went into effect, establishing guidelines for the management and tracking of hazardous waste. It deals with the trash that is regarded to pose a high risk to the environment or human health and hence requires special handling or treatment. Chemicals and solvents are examples of hazardous waste kinds specified in the List of Waste Regulations. The movement of hazardous waste is governed by these laws, which include a documentation system.

4.7.2 Malaysia

In Malaysia, HCW management is overseen to be complied with by the health-care managers subjected to the Environmental Quality Act (EQA) 1974. All guidelines relevant to handling national classification of clinical and related wastes arising from medical, nursing, dental, veterinary, or similar practices are administered by the Department of Environment. In order to exercise the powers conferred by sections 21 and 51 of the EQA 1974, the regulations are cited as Environmental Quality (Scheduled Wastes) Regulations 2005.

4.7.2.1 Environmental Quality Act 1974

Under section 21 [Power to specify conditions of emission, discharge, etc.], the acceptable conditions for any discharge of environmentally hazardous substances, which includes HCW in any area, will be determined by the Minister.

The Minister, after consultation with the Council, may adopt regulations for or with respect to the following requirements under section 51 [Regulations], in addition to and not in derogation of any of the authorities contained in any other provisions of this Act. Some of the requirements are listed here (not in order):

1. prescribing standards or criteria for determining when any matter, action or thing is poisonous, noxious, objectionable, detrimental to health, or within any other description referred to in this Act.
2. prohibiting the discharge, emission, or deposit into the environment of any matter, whether liquid, solid, or gaseous and prohibiting or regulating the use of any specified fuel.
3. prescribing ambient air quality standards and emission standards and specifying the maximum permissible concentrations of any matter that may be present in or discharged into the atmosphere.
4. prescribing ambient water quality standards and discharge standards and specifying the maximum permissible loads that may be discharged by any source into inland waters, with reference either generally or specifically to the body of waters concerned.
5. regulating the establishment of sites for the disposal of solid and liquid wastes on or in the land.
6. Scheduled wastes shall, as far as practicable, before disposal, be rendered innocuous.
7. Generation of scheduled wastes shall be reduced using the best practicable means.
8. Scheduled wastes may be stored, recovered, and treated within the premises of a waste generator.

9. Incineration, disposal, off-site storage, and off-site treatment shall only be carried out at prescribed premises licenced by the DOE.
10. Use of durable waste containers with clear labels. Storage of wastes shall be proper and adequate.

4.7.2.1.1 Environmental Quality (Scheduled Waste) Regulations 2005

There are 15 regulations that must be followed in order to execute the powers granted by sections 21 and 51 of the EQA 1974. Among others, the following subsections are important with respect to HCW:

(4) Disposal of garbage that has been scheduled.

All scheduled wastes must be disposed of at a specified location and rendered harmless prior to disposal, according to this regulation.

(5) Wastes that have been scheduled for treatment.

The whole content and residual treatment of the scheduled wastes must be carried out in prescribed premises or on-site facilities.

(6) Material or product recovery from scheduled trash.

Any recovery of hazardous health-care waste should take place in designated areas and at on-site recovery facilities.

(7) Implementation of particular waste management procedures.

A request can be made to the Director-General of the Department of Environment Malaysia with a non-refundable charge if the health-care management would like the clinical waste to be managed in a manner other than that specified in the regulation.

(8) The generation of garbage is the responsibility of the individual.

All waste generators are responsible for managing clinical waste in compliance with the Director-General of the Department of Environment Malaysia's recommendations in all aspects of storage, treatment, recovery, packaging, labelling, and transportation at designated locations.

(10) Wastes that are scheduled to be disposed of must be labelled.

(11) The waste generator must retain a record of all scheduled wastes.

(12) Waste generators, contractors, and occupiers of prescribed locations must report information.

(13) Wastes moved outside the grounds of the waste generating must be accompanied with information.

(14) Accidental discharge or spill.

The guidelines include information on how to properly handle and manage HCW from both private and public health-care facilities.

4.7.2.1.2 Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Order 1989

Under this Order, "Land treatment facility" means premises occupied or used for the retrieval of material or product from any scheduled waste that is not produced on those premises; "off-site treatment facility" means premises occupied or used for the processing of any scheduled waste that is not produced on those premises;

Table 4.24 Clinical Waste in the First Schedule, Environmental Quality (Scheduled Wastes) Regulations 2005 [29]

Waste code	Waste that may contain either inorganic or organic constituents
SW 403	Discarded drugs containing psychotropic substances or containing substances that are toxic, harmful, carcinogenic, mutagenic, or teratogenic.
SW 404	Pathogenic wastes, clinical wastes, or quarantined materials.
SW 421	A mixture of scheduled wastes
SW422	A mixture of scheduled and non-scheduled wastes

"scheduled wastes" means any waste that falls into the categories of waste listed in the First Schedule to the Environmental Quality (Scheduled Wastes) Regulations.

According to Section 18 of the EQA 1974, each prescribed establishment must be licenced. The following premises are prescribed as those whose occupation or use by any individual is an offence under the Act unless he is the holder of a licence issued in respect of those premises:

1. Off-site storage facilities, off-site treatment facilities, off-site recovery facilities, and scheduled waste incinerators are all examples of off-site storage facilities.
2. Secure landfills; and land treatment facilities.

4.7.2.1.3 Environmental Quality (Prescribed Premises) (Scheduled Wastes Treatment and Disposal Facilities) Regulations 1989

This regulation provisions concerning the treatment and disposal of HCW, which falls under the scheduled waste category in the First Schedule to the Environmental Quality (Scheduled Wastes) Regulations 1989, now updated as Environmental Quality (Scheduled Wastes) Regulations 2005. Under this First Schedule, the following codes related to clinical waste under this regulation are listed in Table 4.24.

4.8 Covid-19 Situation and Its Impact on HCW Management

Coronavirus disease 2019 (COVID-19) was first found in Wuhan, China, in December 2019 [31] after being spread by the SARS-CoV-2 virus, which produces an acute respiratory disease [32–34]. There is now a Public Health Emergency of International Concern (PHEIC) [35] since the virus has spread to so many countries. Globally, the epidemic remains a severe threat to public health. The rapid rise in the number of people infected with COVID-19 and the disease's high transmission rate has resulted in a large number of hospitalisations. In turn, this has led to a dramatic increase in the amount of health-care-related trash generated. Since the COVID-19 pandemic, the use of personal protective equipment (PPE) has expanded significantly, which has resulted in an increase in HCW [36, 37]. To prevent the virus from

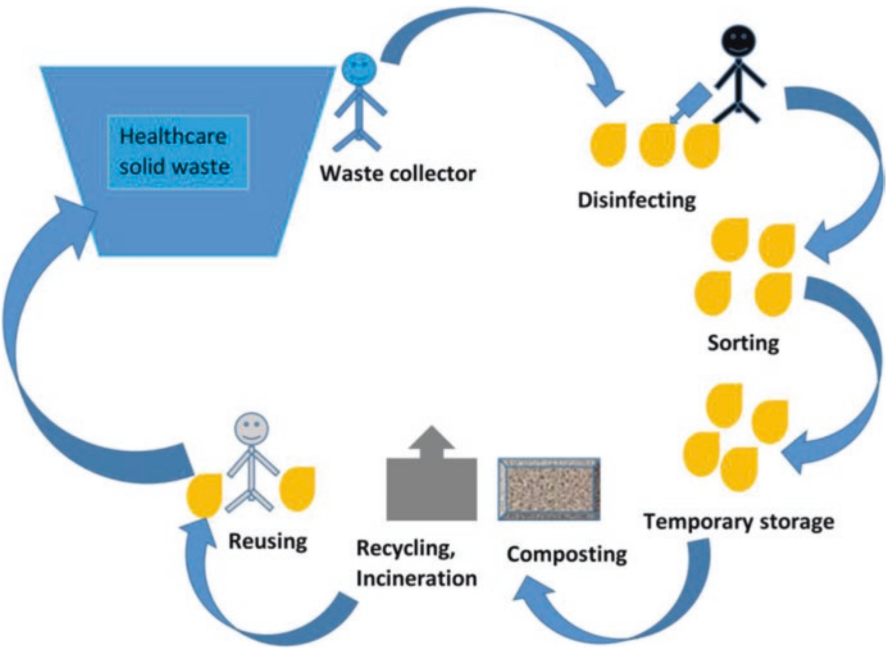

Fig. 4.20 The spread of the COVID-19 virus is aided by the improper treatment of health-care waste [38]

Table 4.25 Details estimated added quantity amount of HCW in each city due to the Covid-19 pandemic [39]

City	Population in a million (World population review)	HCW generated (tonnes/day before Covid-19)	Estimated additional HCW generation (tonnes/day during Covid-19)	Percentage of an increase due to Covid-19
Manila	14	47	280	496
Jakarta	10.6	35	212	506
Bangkok	10.5	35	210	500
Hanoi	8	27	160	493
Kuala Lumpur	7.7	26	154	492

spreading further, it is critical to expand the handling capacity for HCW [34]. Garbage pickers, waste staff, health workers, patients, and the general public are all at danger of infection from harmful microorganisms when the trash is not properly treated (Fig. 4.20). Several countries have put in place safety measures to combat contamination and handle medical waste; however, these are insufficient and vary depending on the environment of the country.

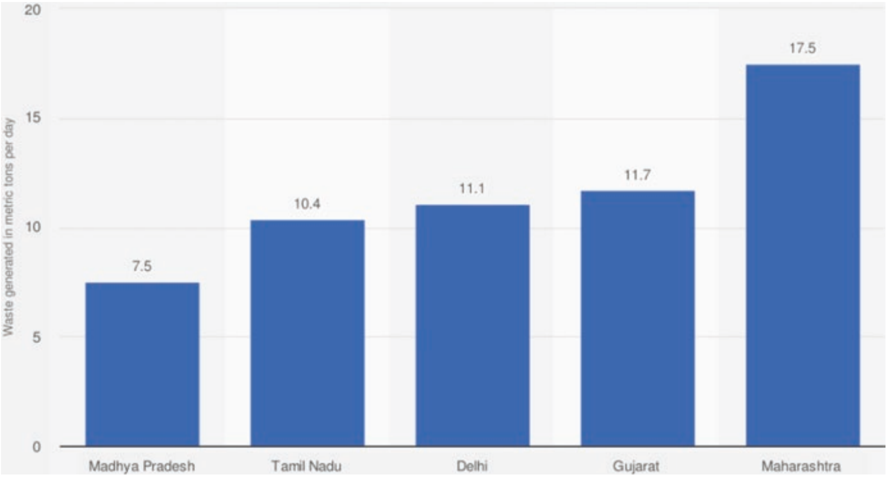

Fig. 4.21 Volume of the coronavirus (COVID-19) biomedical waste generated across India as of July 2020, by state (in metric tonnes/day) [40]

Table 4.25 shows the increased HCW expected in each city as a result of the Covid-19 pandemic [39]. Globally, the COVID-19 epidemic has resulted in an increase in HCW. HCW generation in Bangkok is estimated to have increased to 160 metric tonnes/day during the crisis, up from 26 metric tonnes previously. This was a nearly 500% gain in a single day. The increased usage of disposable personal protective equipment (PPE), such as masks, is one of the reasons for the rapid increase in waste [1].

Figure 4.21 shows the volume of the coronavirus (COVID-19) biomedical waste generated across India as of July 2020 by state (in metric tonnes/day).

The volume of coronavirus (COVID-19) biomedical waste generated in India was 101 metric tonnes/day as of July 2020. With about 17.5 metric tonnes/day, Maharashtra, in the southwest, was the largest producer of medical waste from the epidemic [40]. The most populous cities, including New Delhi, Mumbai, Bangalore, Chennai, and Hyderabad, are the most affected by COVID-19. A substantial amount of COVID-19-related biological waste is generated in India, according to statistics obtained by NDTV [41] on September 18, 2020. (over 100 tonnes/day). About 17% of the total COVID-19-related BMW is attributed to Maharashtra. India's daily trash output has surpassed 850 tonnes. Information on the monthly production of COVID-19-related BMWs in various Indian states may be found in Table 4.26 (from June 2020 to December 2020). Infrastructural and personnel resources in the country aren't sufficient to deal with the influx of BMWs. It was impossible to eliminate the daily 700 tonnes of rubbish with the 198 CBMWFs and 225 captive incinerators that existed. Additional BMW caused havoc with BMW's inventory. BMW management workers are working longer hours in order to meet this demand. From 25 to 349 metric tonnes/day of BMW during the months of May–July, the amount is expected to have doubled during the months of August–October,

Table 4.26 Details on the generation of COVID-19 related BMW in Indian States/UTs from June 2020 to December 2020 [41]

S. No.	States/UTs	Generated BMW (in tonnes)							Total number
		June 2020	July 2020	August 2020	September 2020	October 2020	November 2020	December 2020	
1	Andaman & Nicobar	0.42	INP	INP	0.42	0.434	0.42	0.43	0
2	Andhra Pradesh	165.48	182.81	118.82	112.35	116.095	317.91	328.51	11
3	Arunachal Pradesh	3.36	3.36	3.80	3.36	3.472	3.36	3.47	0
4	Assam	28.38	20.68	12.57	62.61	51.739	50.07	23.41	1
5	Bihar	6.84	20.76	41.54	45.36	44.64	28.08	23.31	4
6	Chandigarh	29.85	5.65	55.34	43.02	73.191	70.83	73.19	1
7	Chhattisgarh	11.19	INP	13.39	9.3	9.61	9.3	9.61	4
8	Daman & Diu	0	INP	0.00	0.48	2.387	1.08	1.15	1
9	Delhi	333.42	389.58	296.14	382.5	365.893	385.47	321.32	2
10	Goa	0.81	0.81	INP	15	7.75	5.43	5.39	0
11	Gujarat	350.79	306.14	360.04	622.89	545.879	423.51	479.57	20
12	Haryana	75.33	184.18	210.69	278.31	238.452	239.4	209.93	11
13	Himachal Pradesh	3.81	12.50	4.94	25.2	28.117	30.03	48.24	2
14	Jammu & Kashmir	10.71	9.77	51.77	57.39	59.303	44.82	35.12	2
15	Jharkhand	INP	INP	2.59	4.8	4.96	4.8	11.63	4
16	Karnataka	84	540.28	588.03	168	218.023	210.99	218.02	26
17	Kerala	141.3	293.32	588.05	494.1	641.979	600.39	542.47	1
18	Lakshadweep	0.3	INP	INP	0.3	0.31	0.3	0.31	0
19	Madhya Pradesh	224.58	5640	106.59	339	308.419	208.65	249.49	13
20	Maharashtra	524.82	1180	1359	524.82	542.314	609	629.30	29

S. No.	States/UTs	Generated BMW (in tonnes)							Total number
		June 2020	July 2020	August 2020	September 2020	October 2020	November 2020	December 2020	
21	Manipur	5.13	0.20	2.09	5.13	5.301	5.13	9.27	1
22	Meghalaya	5.1	1.74	6.34	9.9	12.028	7.65	8.56	2
23	Mizoram	4.2	INP	INP	4.2	3.224	3012	3.22	0
24	Nagaland	3.6	3.4	3.10	2.85	3.317	1.86	2.29	0
25	Odisha	31.86	106.63	109.19	134.01	183.458	222.66	125.58	5
26	Puducherry	18.63	35.82	41.54	63	58.652	28.74	17.11	1
27	Punjab	48	35.59	21.19	234.42	149.606	96.51	86.99	5
28	Rajasthan	177	7.15	50.43	145.08	171.554	141.93	105.93	8
29	Sikkim	6	0.20	0.30	6	4.216	3.69	2.45	0
30	Tamil Nadu	312.3	401.29	481.10	543.78	524.179	300.75	251.22	8
31	Telangana	12.3	10.50	24.04	188.82	144.801	103.89	68.82	11
32	Tripura	0.45	INP	INP	0.45	0.465	0.45	0.47	0
33	Uttarakhand	0.45	0.82	41.45	21.72	108.96	56.76	76.26	2
34	Uttar Pradesh	210	307.54	408.86	507.15	478.082	316.71	276.46	18
35	West Bengal	195	136.37	235.12	434.76	486.793	330.84	279.06	6
Total		3025.41	4253.46	5238.45	5490	5597	4864.53	4527.55	198

Table 4.27 General of coronavirus disease (Covid-19) clinical waste (CW) by country [42]

Country	Amount of waste generated during COVID-19 (kg/bed/day)	Percentage of increase in CW generation Covid-10 pandemic
Taiwan	0.9–2.7	No data
Jordan	3.95	1000%
Wuhan, people's Republic of China	0.6–2.5	213%
Bandung, Indonesia	2.2	17.1%
Penang, Malaysia	0.4–1.0	27%
Thailand	2.9	No data
Mexico	2.0–2.2	No data

according to a Supreme Court report. Segregation at the generation site is currently weak due to a rapid increase in generation, which increases the risk in the generation and increases environmental hazards. In addition, the lack of adequate safety measures for BMW personnel in India is a major problem. Approximately five million sanitation workers (Safai karamchari) are currently cleaning the country and performing their tasks. As a result, they lack adequate personal protection equipment. As a result, the local community is at risk since these workers are in danger. Scientists have found that the virus can survive for up to 72 h on the surfaces of metals and sharps, posing a major risk to workers who regularly gather garbage for more than 24 h. Ragpickers, or karoles, make up a sizable portion of India's population. However, they are not adequately informed or aware of the precautions that must be taken. Over tens of thousands of trash, collectors have fallen victim to the outbreak, with hundreds of them dying as a result.

Agamuthu and Barasarathi [42] have summarised (Table 4.27) data from various sources on coronavirus effects on clinical waste generation in a few countries.

In response to the Covid-19 outbreak, Table 4.28 highlights existing methods for health-care waste separation, storage, and transportation in a number of countries. Table 4.29 describes the handling and disposal of Covid-19 waste in selected countries.

4.9 Conclusion

Increased attention and diligence are needed in the management of health-care waste (HCW) to avoid the health consequences of poor practice, such as exposure to infectious agents and toxic substances. When it comes to waste management, a good HCW management team should have a system that follows a hierarchy that prioritises prevention over disposal. Waste segregation, reuse, and recycling, where applicable, can all be used to reduce the volume of hazardous waste.

Table 4.28 Current practices in selected countries for health-care waste separation, storage, and transportation in response to the Covid-19 epidemic [1]

Country	Practices
Afghanistan	• Separate health-care wastes such as general waste, anatomical waste, and other infectious waste at the point of generation
	• Collect sharps (used auto-disable syringes) separately in yellow boxes
	• Designate a storage area at health-care facilities (separated wastes from each ward are transported by wheeled trolleys)
	• Transport safely packed waste with adequate labelling for off-site treatment and disposal
Bangladesh	• Use separate colour-coded bins (Black: Non-hazardous waste, Red: Sharp waste, Yellow: Infectious/pathological waste, etc.)
	• Store the bins on their premises, to be collected mostly on a daily basis, by separate covered vehicles, for transportation to a treatment site
India	• Use dedicated trolleys and collection bins in COVID-19 isolation wards
	• Waste contaminated with blood/body fluids of COVID-19 patients to be collected in a yellow bag for home quarantined households.
	• Paste a label "COVID-19 Waste" on these items
	• Disinfect with 1% sodium hypochlorite solution daily on (inner and outer) surfaces of containers/bins/trolleys
	• Depute dedicated sanitation workers separately for biomedical waste and general solid waste collection and timely transfer to temporary storage
	• Use a vehicle with GPS and barcoding systems for bag/containers containing HCW for waste tracking, as well as having a label of "Biohazard" or "Cytotoxic" on the vehicle
Indonesia (some local governments)	• Identify the means of classification and communication (symbols, labels)
	• Designate COVID-19 infectious bins
	• Conduct internal sterilisation/disinfection before bags are tied
	• Disinfect bags before collection
	• Label bags "Danger, do not open".
	• Schedule the transportation of waste by the cleaning service every day on weekdays
Japan	• Separate infectious, non-infectious, and general wastes
	• Separate sharps from other infectious wastes with a proper container
	• Seal the container, which is easy to use and hard to break
	• Transport by a designated cart to avoid scattering and spilling wastes within a facility
	• Use short storage periods as much as possible
	• Separate infectious wastes and store them from other wastes in the storage room
	• Access to the storage room only by authorised persons
	• Apply clear labelling, with notification given on bags for infectious wastes at the storage room

(continued)

Table 4.28 (continued)

Country	Practices
Kenya	• Place infectious waste in yellow bins with liners marked "Danger Hazardous Medical"
	• Never sort through contaminated wastes
	• Reuse reusable items only after proper disinfection
	• Tie bags when they are 2/3 full, and disinfect the waste and place it in a designated area for collection
	• Store waste in specified areas with restricted access
Malaysia	• Not separate COVID-19 waste with other infectious waste
	• Equip the cold room in some bigger health-care facilities
	• Collect daily or 3 times a week depending on the quantity
	• Transport only by a special lorry licenced to transport hazardous waste
Mexico	• Same protocol with other infectious waste according to the Mexican Standard #087)
	• Use a container hermetic and polyethylene bag according to the type of health-care wastes
	• Use the bag with translucent red polyethylene of minimum calibre 200 and translucent yellow colour of minimum 300 gauge, waterproof, and with a heavy metal content of not more than one part per million (PPM) and free of chlorine
	• Fill to 80% of the capacity of the bag, and close and transport to the temporary storage site
	• Mark with the universal risk symbol and the legend biological
	• Designate the temporary storage of waste biological-infectious dangerous.
	• Stored biological-infectious hazardous waste separated from the patient areas, and medicine warehouse, etc., accessible for collection and transport without risks of flood and entry of animals, with signs alluding to their dangerousness, access only responsible personnel
	• Not compact hazardous biological-infectious during its collection and transportation
	• Use the collection vehicle with a closed box and hermetic vehicle and operate with cooling systems to keep residues at a maximum temperature of 4 °C (four degrees Celsius) and with mechanised loading and unloading systems
	• Must not be mixed with any other type of municipal or industrial origin during transportation, hazardous biological-infectious waste
Nepal	• Designate waste storage in health facilities (some meet the standard, but some are unmanaged)
	• Use specific trollies for transportation within the hospitals
	• Use specific vehicles for transportation from health-care facilities to treatment WMSPs

(continued)

Table 4.28 (continued)

Country	Practices
South Africa	• Minimise the volume of HCW at source
	• Remove ¾ full sealed box sets, and store at the central storage area prior to collection for treatment and disposal
	• Secure space with the sign of "Suspected COVID-19"
	• Storage on-site in the following manner: sufficient secure capacity, prevent access to these areas to unauthorised persons, mark with warning signs on, or adjacent to, the exterior of entry doors, gates, or lids, secure by use of locks on entry doors, gates, or receptacle lids, and prevent odour
	• Use plastic bags with a capacity of 60 L or more, and at least 80 µm in thickness
	• Ensure that the time between collection of a consignment by transporter from the relevant generator's premises and the treatment of that health-care risk waste does not exceed 72 h if pathological waste is unrefrigerated
Thailand (Chiang Rai)	• Separate into two types: (1) sharp items; (2) non-sharp items (COVID-19 waste under the non-sharp items)
	• Disinfect and double bags
	• Designate a specific storage area
	• Send waste from community health-care facilities to district health-care facilities once a week
	• Temperature-controlled storage available at the district level
	• Transport by licensed WMSPs (require temperature-controlled vehicle)
	• Treat within 48 h after being transported
	• Disinfect vehicles and bins daily with NaClO

Table 4.29 Covid-19 waste treatment and disposal in selected countries [1]

Country/city	Covid-19 waste generated from a health-care facility	Covid-19 waste generated from household/ quarantine location
Bangladesh	• Incinerator	• N/A
India	• Common biomedical waste treatment facility (CBWTF)	• Hand over to waste collector identified by urban localities or as per the prevailing local method of disposing of general solid waste.
	• Permit disposal by deep burial only in rural or remote areas without CBTWF facilities	• Urban local body (ULB) shall engage CBWTF operator for the ultimate disposal of biomedical waste collected from quarantine home/home care of waste deposition centres or from doorsteps as may be required depending on the local situation. ULB shall make an agreement with CBWTF in this regard.
	• In case of generation of a large volume of yellow colour coded (incinerable) Covid-19 waste beyond the capacity of existing CBWTF and the captive BMW incinerators, permit HW incinerators at existing treatment, storage, and disposal facilities (TSDFs) or captive industrial incinerators if any exist in the State/Union territory. In such case, ensure separate arrangements for handling and waste feeding	

Table 4.29 (continued)

Country/city	Covid-19 waste generated from a health-care facility	Covid-19 waste generated from household/ quarantine location
Indonesia (some local governments)	• Mostly incineration, disinfect at source and transport to the disposal sites or open burning (if no incinerator), hazardous waste landfill	• Directly burn easily at home • Collect and transport by office staff to the cement factory incinerator for the burning process (Padang)
Japan	• Incineration, melting, steam sterilisation (autoclave) followed by shredding, dry sterilisation followed by shredding, disinfection followed by shredding and disposing of the specific sanitary landfill	• Mix recyclable items with other combustible waste (and incinerate) • Discharge incombustible waste after 7-day storage at source
Kenya	• Incineration, microwave, crude dumping of ash and microwaved end-product at the municipal dumpsite	• N/A
Malaysia	• Mostly incineration	• Transport all ash from the incineration plants to the hazardous waste treatment centre and solidify with cement to be disposed of in a special landfill
Mexico	• Treat and dispose of as normal hazardous HCW (autoclave, incinerator, radio wave, etc.)	• Incinerated or confined in an emergency cell in a landfill and earth covered every day
Nepal	• Mostly buried, small-scale incineration, or dumped backyard, municipal landfill, or other areas	• N/A
Saint Lucia	• Steam sterilisation, autoclave, chemical disinfection (some)	• N/A
South Africa	• Incineration, non-burn technologies (autoclaves, converter, microwave)	• Covid-19 waste generated in a household is managed as part of municipal waste • Waste generated at a quarantine facility is treated as HCW, and most are treated at incineration or non-burn treatment facility
Sri Lanka	• Incinerator	
Thailand (Chiang Rai)	• Incinerator, autoclave, waste management service provider (WMSP), sanitary landfill	• N/A

It is critical that all waste workers, including municipal employees, wear personal protection equipment (PPE) and practise proper hand hygiene when handling hazardous materials (HCW). From a sustainability perspective, it is important to consider the informal sector (which typically plays a significant role in waste management). For health-care facilities and those in the informal sector, such as waste collectors, HCW management training and awareness-raising are critical. In order to continually improve HCW management, stakeholders should engage in regular discussions to exchange ideas, statistics, and information, as well as lessons learned. Rapid response is also possible in an emergency.

Medical waste incineration is the most applied treatment of hazardous HCWs, together with autoclaving and microwaving, steam treatment integrated with internal mixing and chemical treatments. All countries should implement a comprehensive system that addresses responsibilities, resource allocation, handling, and disposal in tandem with strong political will. Progress will be gradual and sustained by raising awareness of the risks associated with HCW and of safe practices; and ensuring that people are protected from hazards when collecting or handling waste, transporting or storing it. For the long-term, universal improvement, government support and commitment are required, but immediate local action can be taken to improve conditions.

All countries should refer to international guidelines for safe HCW management, which should be made available to the general public. Covid-19 has taught a good lesson to the world on how important it is to be pre-prepared with appropriate protocols in managing and controlling not only the infection but also handling all health aspects, including the HCW management. HCW general ideas and criteria for limiting infectious waste should be followed during the future pandemic.

Glossary

ADR ADR is an abbreviation for "Accord européen relatif au transport international des marchandises dangereuses par route", which translates as "The European Agreement concerning the International Carriage of Dangerous Goods by Road". The international term ADR has been so widely used in the transport industry that almost anyone in the industry understands what is meant, regardless of their country of origin.

Best Environmental Practices (BEP) Best Environmental Practice (BEP) means the application of the most appropriate combination of environmental control measures and strategies.

Common biomedical Waste Treatment Facility (CBWTF) A Common Biomedical Waste Treatment Facility (CBWTF) is a set-up where biomedical waste, generated from a number of health-care units, is imparted necessary treatment to reduce adverse effects that this waste may pose. The treated waste may finally be sent for disposal in a landfill or for recycling purposes.

Genotoxic Waste Genotoxic wastes are a subset of hazardous waste that may have mutagenic, teratogenic, or carcinogenic properties. This kind of wastes include residues of certain cytostatic drugs or vomit, urine and faeces from patients treated with cytostatic drugs, chemicals and radioactive material.

Half-Life The time taken for the radioactivity of a specified isotope to fall to half its original value. For example, "iodine-131 has a half-life of 8.1 days".

Personal Protective Equipment (PPE) Personal Protective Equipment (PPE) is equipment that will protect the user against health or safety risks at work. It can include items such as safety helmets, gloves, eye protection, high-visibility clothing, safety footwear, and safety harnesses. It also includes respiratory protective equipment (RPE). The hazards addressed by protective equipment include physical, electrical, heat, chemicals, biohazards, and airborne particulate matter.

Public Health Emergency of International Concern (PHEIC) A Public Health Emergency of International Concern (PHEIC) is a formal declaration by the World Health Organization (WHO) of "an extraordinary event which is determined to constitute a public health risk to other States through the international spread of disease and to potentially require a coordinated international response", formulated when a situation arises that is "serious, sudden, unusual, or unexpected", which "carries implications for public health beyond the affected state's national border" and "may require immediate international action".

Puskesmas Puskesmas (Indonesian: Pusat Kesehatan Masyarakat, English: Community Health Centre) are government-mandated community health clinics located across Indonesia. They are overseen by the Indonesian Ministry of Health and provide health-care for the population on the sub-district level.

Regulated Medical Waste (RMW) Regulated Medical Waste (RMW)—also known as "biohazardous" or "infectious medical" waste—refers to wastes that contain blood, body fluids, or other potentially infectious materials like sharps, as a result posing a risk of transmitting infection.

SARS-CoV-2 Virus Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) is the coronavirus that causes COVID-19 (coronavirus disease 2019), the respiratory illness responsible for the ongoing COVID-19 pandemic. The virus previously had a provisional name, 2019 novel coronavirus (2019-nCoV), and has also been called human coronavirus 2019 (HCoV-19 or hCoV-19). First identified in the city of Wuhan, Hubei, China, the World Health Organization declared the outbreak a Public Health Emergency of International Concern on 30 January 2020 and a pandemic on 11 March 2020. SARS-CoV-2 is a positive-sense single-stranded RNA virus [14] that is contagious in humans. As described by the US National Institutes of Health, it is the successor to SARS-CoV-1, the virus that caused the 2002–2004 SARS outbreak.

Stockholm Convention's BAT Under the Stockholm Convention, Best Available Techniques (BAT) are defined as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for release limitations designed to prevent and, where that is not practicable, generally to reduce releases of chemicals listed in Part I of Annex C and their impact on the environment as a whole".

UNDP, United Nations Development Programme The United Nations Development Programme (UNDP) is a United Nations organisation tasked with helping countries eliminate poverty and achieve sustainable economic growth and human development. Headquartered in New York City, it is the largest UN development aid agency, with offices in 170 countries.

WHO, World Health Organization World Health Organization (WHO) is the United Nations agency founded in 1948 that connects nations, partners, and people to promote health, keep the world safe, and serve the vulnerable—so everyone, everywhere can attain the highest level of health.

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