Chapter

# Nonbiodegradable Hospital Waste Burden and Implications

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## Abstract

Hospitals and other healthcare facilities are very essential for the cure and care of persons suffering from health issues and also to promote health in society. As the health care services are improving and increasing their reach even in underdeveloped countries, so is the problem of health care waste (HCW) as hospitals generate a relatively huge amount of HCW, which consists of general as well as hazardous waste. The persons handling HCW are at immediate risk, followed by persons residing near HCW dumping/processing areas and the general public. Infectious HCW is a major threat to the health of humans and animals as it has the potential to spread various infectious diseases to the human and animal population. Due to the uncontrolled use of disposable nonbiodegradable materials by healthcare systems and their processing or lack of it, the HCW has emerged as one of the major sources of environmental pollution including the emission of the significant amount of greenhouse gases, which stands from 3 to 10% of total emissions of nations. HCW also leads to leaching chemicals, heavy metals like Pb, Cd, Cr, radioactive substances, and even generating carcinogens like dioxin in the environment contaminating air, soil, and water in general and especially in areas surrounding HCW dumping or processing affecting health and quality of life of not only of humans but cohabiting flora and fauna in those areas. Thus, the HCW is becoming one of the major sources of environmental pollution and collectively contributing to the problem of global warming. The HCW needs to be given the desired attention and priority in actions and policy. The chapter focuses on sources, types, and various environmental and health hazards related to HCW, its global environmental impact and management strategies for minimum effects with an eco-friendly and sustainable approach.

**Keywords:** health care waste, biodegradable, infectious waste, sharp, cytotoxic waste, radioactive waste, environment, carbon emission

## 1. Introduction

A biodegradable material can be decomposed by natural microorganisms, while nonbiodegradable material cannot be decomposed by natural microorganisms. The former will not be adding to pollution as it will be slowly broken down, but the latter acts as a source of pollution as it will remain as such in the environment for a very long time.

| S. no. | Biodegradable waste | Nonbiodegradable waste |
|---|---|---|
| 1 | Decomposed and degraded by microbes. | Not decomposed and degraded by microbes. |
| 2 | Degradation process waste is rapid. | Degradation process is extremely slow. |
| 3 | Do not accumulated in environment but are cleaned up in a short time. | Accumulated in environment and are not easily cleaned up. |
| 4 | Becomes part of biogeochemical cycles, and are rapidly turned over in nature into useful components. | Never enter into biogeochemical cycles, and are therefore toxic and hazardous for nature. |
| 5 | Produce energy manure, compost, and biogas. | Can be separated and recycled and reused. |
| 6 | Decomposition process is natural and very affordable. | The process of treatment of waste is very expensive. |

**Table 1.**
*Difference between biodegradable and nonbiodegradable waste.*

Biodegradable waste typically originates from some kind of organic materials from plant or animal sources and is commonly found as green waste, food waste, paper waste, and other biodegradable materials, like human waste, manure, sewage, slaughterhouse waste, etc.

Nonbiodegradable wastes are not decomposed or dissolved by natural biological processes. Most of the inorganic waste is nonbiodegradable. The major drawback of technological advancements in the creation of materials that nature cannot decompose, i.e. nonbiodegradable. Prominent examples of nonbiodegradable wastes are polyethylene and plastics, which are commonly used materials in almost every field, including the healthcare system. Now a day's improved, temperature resistant and more durable plastics are being produced making them even more long-lasting pollutants. Cans, metals, and chemicals form other chunks of nonbiodegradable waste.

It remains on earth for thousands of years unchanged and the threat caused is more significant. It not only causes air, water, and soil pollution but also act as a measure health hazard causing diseases like cancer (**Table 1**).

## 2. Health care waste (HCW)

The hospitals are considered as noble places, which treat sick persons and work for the health of society. The various adverse effects like high waste generation by them, their unplanned disposal, and their impact on the health of humans, animals, and the environment were generally neglected. A well-established and well-accepted fact is that Health care waste (HCW) or hospital waste is a potential challenge not only for the health care employees but for the general public and animals and plants of the surrounding environment.

HCW is anything that is produced by health care centers either of biological or nonbiological origin that needs to be discarded and is not intended for further use. It can be generated during the diagnosis, treatment, immunization, healthcare-related research activities, any such activity in healthcare centers, or hospitals. HCW may be composed of bio-waste like bodily parts and fluids, used medical materials, and also nonmedical general waste material which may be nonbiodegradable. Various sources of HCW are enlisted in **Table 2**.

| Major sources | Minor sources |
|---|---|
| **Hospitals/clinics/nursing homes** | • Physicians' offices |
| • Teaching University hospital | • Specialized health-care establishments |
| • General and District hospital | • Door to door health services |
| • Primary healthcare center | |
| • Medical emergency services | |
| • Other health-care establishments | |
| • Obstetric and maternity hospitals | |
| • Dialysis centers | |
| • Dispensaries | |
| **Medical and biomedical laboratories** | • Dental clinics |
| • Diagnostic centers | |
| • Autopsy centers | |
| • Medical research & training centers | • Psychiatric hospitals |
| • Biotechnology research centers/institution/production units | • Disabled persons' institutions |
| • Animal houses | • Acupuncturists<br>• Chiropractors |
| • Blood banks and blood collection services | • Ambulance services |
| • Home where health care is being provided | • Home treatment |
| • Mortuaries | • Funeral services |
| | • Cosmetic ear-piercing and tattoo parlors |
| | • Illicit drug users |

**Table 2.**
*Sources of biomedical waste.*

## 3. Classification of biomedical waste

The medical waste generated is a multi-component waste and varies from regular nonhazardous waste. It consists of general items, biological materials to chemicals

| S. no. | The EPA USA | The EU | The UK government | World Health Organization (WHO) |
|---|---|---|---|---|
| 1 | **General waste:** the major portion of medical waste consists of typical domestic and office waste. | Infectious waste including sharps. | **Infectious waste**: any waste generated by the treatment of patients or containing any infectious body fluids or material. | **Infectious waste:** any thing that's infectious or contaminated. |
| 2 | **Infectious waste:** any waste having potential to cause an infection e.g. blood, human tissue, or anything contaminated with bodily fluids, etc. | Pathological waste | **Cytotoxic/cytostatic waste**: drugs and materials that are cytotoxic and/or cytostatic and the items that are in contact with toxic or carcinogenic agents etc. | **Sharps**: waste like needles, scalpels, broken glass, razors, etc. |

| S. no. | The EPA USA | The EU | The UK government | World Health Organization (WHO) |
|---|---|---|---|---|
| 3 | **Hazardous waste:** waste that is potentially dangerous but non-infectious e.g. sharps, discarded surgical equipment, some chemical waste, etc. | Chemicals & pharmaceutics | **Medicinal waste**: All types of noncytotoxic medicine, pills,creams, etc. | **Pathological waste:** Human or animal tissue, body parts, blood, fluids, etc. |
| 4 | **Radioactive waste: w**aste generated during radioactive treatments, like in cancer and due to the use of medical equipment, which use radioactive substances. | Cytotoxic & radioactive waste | **Anatomical waste**: waste from a human or animals including body parts, blood bags, etc. | **Pharmaceutical waste:** discarded, unused or expired medicines like tablets, capsules, syrups, creams, etc. |
| 5 | | Nonrisk general waste | **Offensive waste**: non-infectious waste that includes sanitary,nappy waste, etc. | **Genotoxic waste:** hazardous waste containing drugs that are cytotoxic and carcinogenic, mutagenic, or teratogenic. |
| 6 | | | **Domestic or municipal waste**: all other general, nonclinical waste. | **Radioactive waste**: waste contaminated with radioactive materials |
| 7 | | | | **Chemical waste**: hazardous waste congaing chemicals, disinfectants, liquid waste from machines, batteries, etc |
| 8 | | | | **General/other waste**: nonhazardous waste containing stationary or other general daily use items. |

**Table 3.**
*Classification of medical waste.*

including radioactive substances. The classification of medical waste, as per EPA (USA), EU, the government of UK, and WHO is depicted in **Table 3**.

All these classifications have commonly focused on Infectious waste, hazardous waste, chemical waste, and general waste. WHO's classification is most elaborate and very specific and generally followed irrespective of country and continent.

## 4. The problem of hospital waste

The healthcare sector can be a great nuisance, if HCW is not given due importance and handled properly and become the worrisome source that emits different greenhouse gases and is home to different pathogens that can cause damage to human and animal health and affect the environment. HCW also is the source of particulate matter and the area close to HCW dumping or processing site has a relatively very high level of the same [1].

Considering the segregation of HCW, the nonhazardous waste usually constitutes 80–85% of the total HCW and hazardous waste is about 15–20% based on rough estimations provided by WHO [2]. HCW is a worldwide issue as the AAMC found that globally approximately 4.4% of all greenhouse gas emissions and over 5 million tons of waste come from hospitals [3].

This estimation needs to be further investigated with respect to the degradation potential of total health care waste as the nonhazardous waste may not be biodegradable. **Table 4** gives the classification of overall HCW based on biodegradation. The list indicates that though the waste may not be hazardous but it may also not be biodegradable thus aggravating the problem of long-term environmental pollution and subsequent effects.

Various studies reported an increased incidence of health issues among employees and the resident population living nearby of waste processing facilities especially living near landfill sites, incinerators, composting facilities, and nuclear installations. Studies also reported that pathogens originating at HCW treatment plants pose a high risk of gastrointestinal infections [4].

| Biodegradable waste | Partially biodegradable waste | Nonbiodegradable waste |
|---|---|---|
| **Human anatomical waste:**<br>•Human tissues<br>•Organs<br>•Body parts | Liquid waste generated from laboratory and washing, cleaning, house keeping | **Sharps:**<br>Needles, syringes, ampoules, scalpels, blades, glass, etc. |
| **Animal waste:**<br>•Animal body parts, tissues, and organs<br>•Carcasses<br>•Animal blood<br>•Waste generated by veterinary hospitals and research centers, colleges, and animal houses | Ash from the incineration of any Biomedical/HC waste | **Solid waste:**<br>Tubings, catheters, intravenous sets, oxygen sets, dialysis sets, PPE gowns, gloves, masks, empty bottles and plastic containers, and polybags<br>Disposable items<br>Materials used during test for diagnostics |
| **Microbiological & biotechnology waste**<br>•Laboratory cultures<br>•Microorganisms specimens or stocks<br>•Unused or partially used vaccines (live or attenuated)<br>•Cell culture (human and animal)<br>•Infectious agents (from research and industry)<br>•Production of Biologicals<br>•Toxins | | **Chemical waste**<br>Chemicals used in the production of drugs and biologicals<br>Unused drugs and medicines<br>Chemical Materials used during surgery<br>Chemicals used in disinfection and cleaning<br>Radioactive waste<br>Insecticides, etc.) |

**Table 4.**
*Biodegradable and nonbiodegradable medical waste.*

Rapid and uncontrolled growth of medical care facilities are resulting in an increase in waste generation because of the marked increase in the use of disposable items and their illegal recycling. Illegal recycling affects the local community, especially health workers, hospital employees, waste processing staff, and rag pickers [5]. A study in Iranian some selected hospitals indicate that the average of total medical waste generated was about 3.48 kg/bed of which approximately 1.039 kg/bed was hazardous-infectious waste, and 2.439 kg/bed-day was general waste [6]. Some studies reported the concern that large quantity of nonbiodegradable HCW such as disposable syringes, infusion bags, IV fluid bottles and administration sets, oxygen masks, etc. Are dumped in-properly by health care facilities and picked up by rag pickers and returned back into the market without any processing, posing a dangerous threat to the health of patients [7]. Exposure to HCW may spread communicable diseases through skin contact, injection, inhalation, and improper sterilization of containers and plastic materials before recycling [8].

HCW directly impacts on the health of the community, healthcare workers, animals, and surrounding environment. The HCW is saturated with infectious and hazardous waste. Impromptu, haphazard, and nonscientific disposal of HCW results in exposing the public in general and healthcare workers in specific to pathogenic waste which can cause different diseases. This also leads to contamination of all components of the surrounding environment by various hazardous content of HCW especially nonbiodegradable. Hence, HCW requires due attention and specific treatment and management prior to its final disposal.

Most of the times, the HCW gets mixed with domestic waste before disposal creating different types of problems in the long run. In economically developing or underdeveloped countries, the public, health workers, and waste processing personnel in particular, are not aware of the hazards of HCW or trained in management of HCW leading to the escalation of dangers of HCW. Also, in these countries, the lack of sufficient funds and proper information and awareness is a barrier for HCW management [9, 10].

One of the problems with HCW is that due to well-developed, superior, and well spread medical facilities available, the quantum of the pollution by HCW is much more than that of developing or poor countries, which have relatively underdeveloped and scarcely available health care systems [11, 12]. However, the global increment of the HCW production worldwide is increasing at an alarming rate, The middle and low-income countries contributing to this as HCW production is sharply increasing due to improved healthcare services and in the wealthy nations, the rapidly aging population

| S. No. | national income level | Type of waste | Annual waste generation (kg/person) |
|---|---|---|---|
| 1 | High-income countries | All of the HCW | 1.1–12.0 |
| | | Hazardous HCW | 0.4–5.5 |
| 2 | Middle-income countries | All of the HCW | 0.8–6.0 |
| | | Hazardous HCW | 0.3–0.4 |
| 3 | Low-income countries | All of the HCW | 0.5–3.0 |
| | | Hazardous HCW | Negligible (0.02–0.1aprox) |

**Table 5.**
*HCW generation and economic status of country.*

| Continent | Mean(kg/bed/day) | Sample size |
|---|---|---|
| Africa | 0.8 | 8 |
| America | 4.41 | 6 |
| Asia | 2–44 | 18 |
| Europe | 3.10 | 10 |
| Combined | 2.57 | 42 |

**Table 6.**
*Healthcare waste generation rates in different continents.*

that need frequent usage of health care systems is increasing HCW generation rate (HCWGR) [13]. **Table 5** illustrate the average rate of HCW generation with respect to the economic status of the country and **Table 6** indicates that of continents [14].

As per WHO report of 2018, in general, hazardous medical waste generation per hospital bed per day in high-income countries is on an average up to 0.5 kg [3].

## 5. HCW and carbon emissions

It is estimated that in the USA alone, 8–9% of the total annual carbon dioxide emissions (33.34 MT) is contributed by the healthcare industry (HCI) [15, 16]. Just to understand the contribution of HCI in $CO_2$ emission, if we consider that the average value of 5% of total carbon dioxide emission is by HCI the amount of carbon dioxide emission by the top 10 carbon dioxide emitting countries in the year 2020 can be of large quantum as is given in the following **Table 7** [17].

The research shows that three groups of countries i.e. North America (29%), East Asia/Pacific (30%), and Europe/Central Asia regions (19%) contribute about 78% of health care emissions. The remaining 22% of global health care emissions is shared by Latin America (6%), South Asia (2%), and the remaining 14% is shared by

| S. no. | Country | Total $CO_2$ Emission (Mt) | $CO_2$ Emission by HCI (Mt) |
|---|---|---|---|
| 1 | China | 11680.42 | 584.02 |
| 2 | United States | 4535.30 | 226.77 |
| 3 | India | 2411.73 | 120.59 |
| 4 | Russia | 1674.23 | 83.71 |
| 5 | Japan | 1061.77 | 53.09 |
| 6 | Iran | 690.24 | 34.51 |
| 7 | Germany | 636.88 | 31.84 |
| 8 | South Korea | 621.47 | 31.07 |
| 9 | Saudi Arabia | 588.81 | 29.44 |
| 10 | Indonesia | 568.27 | 28.41 |
| Total | | | 1223.45 |

**Table 7.**
*Top ten countries with $CO_2$ emission rates and contribution of HCS*

| S. no. | Primary factor | Secondary factor | Impact |
|---|---|---|---|
| 1 | Increased $CO_2$ level | Air pollution | Asthma, cardiovascular disorders, effect are generally more prominent in persons having lung and heart diseases. |
| | | Increased allergens | Respiratory allergies, asthma, skin disorders, tiredness with minimum physical activity. |
| 2 | Rising temperature | Extreme hot conditions | Disorders related to heat and illness and may be deaths, cardiac disorders including cardiovascular failure. |
| | | Severe weather conditions | Migration and social effects, injuries, mental health impacts, and fatalities. |
| 3 | Rising sea level | Impact on water quality | Infections like cholera, leptospirosis, cryptosporidiosis, campylobacter, and algal growth. |
| | | Food and water supply impact | Food and drinking water problems, malnutrition, diarrheal, and other infective diseases. |
| 4 | Extreme weather conditions | Environmental degradation | Disturbed weather cycles, food and water supply problems, increased diseases, migration, civil conflict, and mental health impacts. |
| | | Changes in ecology (especially vector) | Changed life cycles and growth in previously unfavorable areas leading to the spread of diseases like malaria, dengue, chikungunya, encephalitis, hantavirus, Rift Valley Fever, Lyme disease, West Nile virus, etc. |
| 5 | Acid rain | Decreased pH of water bodies | Decreased portability and utility e.g. not good for swimming, digestive, and skin problems. |
| | | Increased particulate matter | Asthma or chronic bronchitis, make it hard for people to breathe, lungs infections. |

**Table 8.**
*Impact of environmental pollution on human health [21].*

the combined health sectors of Sub-Saharan Africa, Middle East, and North African countries [18].

If we consider HCI a country, it would be at least the fifth-largest emitter of greenhouse gases on the planet. The HCI's carbon footprint can be the same as the emissions of 514 coal-fired power plants [19].

Studies have reported that greenhouse gas emissions from the health sector in various countries range from 3 to 10% of the national emissions. The energy consumption and other waste generation make it a significant factor in changing climatic conditions due to various pollutions. US Environmental agency has reported that HCW is the third major cause of dioxin pollution and 10% of overall mercury emission. The burning of medical waste such as plastic materials, which are generated from polyvinyl chloride (PVC) products is the major producer of dioxin [20]. The effect of climate change has a multifaceted effect on human health which is summarized in **Table 8**.

## 6. Health hazards of carbon emissions

Exposure and inhalation of CO/CO2 lead to a variety of health issues which include difficulty in breathing, increased heart rate, profound sweating, tiredness, restlessness, dizziness, headaches, a tingling sensation, hypertension, coma,

asphyxia, and convulsions. Continuous exposure to CO in the closed area may even lead to death.

Higher average temperatures and changes in weather disturb rain and snow patterns which leads to the migration of invasive species to new areas. Pathogens and even their hosts which were not able to survive low temperatures will spread to new areas as the average temperature rise due to global warming. Insect pest infestations of plants and crops will increase as pests will be able to take advantage of weakened plants due to atmospheric and weather conditions (**Table 9**).

Marine animals are severely affected by the increase in carbon dioxide in the atmosphere. This is because the ocean absorbs $CO_2$ in the atmosphere and becomes more acidic. Though the increase of $CO_2$ in the ocean may have little impact on big marine animals, marine phytoplankton multiplies rapidly with more $CO_2$, and more phytoplankton support larger aquatic animal populations.

The major impact of a more acidic ocean is on animals like corals, sea urchins, and mollusks that produce calcium carbonate shells. Acidification not only causes difficulty for these animals to produce shells but cause the shells to actually dissolve due to the change in the chemical balance of ocean water. Decreased number of shelled animals can impact the ocean ecosystem and trigger a chain reaction in wide range of organisms that depend on these animals for their food (**Table 10**).

| $CO_2$ level | Conditions |
|---|---|
| 400 ppm | Normal level of outdoor air. |
| 400–1000 ppm | Typical level is found in normally populated spaces having good air circulation. |
| 1000–2000 ppm | Poor air quality is prominently indicated by complaints of drowsiness. |
| 2000–5000 ppm | Health issues like increased heart rate, respiratory disorders, slight nausea, poor concentration, loss of attention, headaches, sleepiness, and stagnant, stale, and stuffy air. |
| 5000 ppm | This is the maximum permissible exposure limit. Toxicity and oxygen deprivation occur. High levels of other gases may be present leading to more severe effects. |
| 40,000 ppm | Very dangerous due to deprivation of oxygen. |

**Table 9.**
*Potential health problems with increased levels of $CO_2$ in the air [22].*

| City/country | Population (Million) | HCW generated | Additional HCW generated due to COVID | % Increase due to COVID |
|---|---|---|---|---|
| Manila | 14 | 47 | 280 | 496 |
| Jakarta | 11 | 35 | 212 | 506 |
| Kuala Lampur | 10.5 | 35 | 210 | 500 |
| Bangkok | 8 | 27 | 160 | 493 |
| Ha Noi | 7.8 | 26 | 154 | 492 |

**Table 10.**
*Increase in waste generation by COVID-19 in some cities.*

According to Practice Green-health, an organization working for more sustainable hospitals, about 25% of the waste generated by hospitals is plastic. The National Health Service (NHS), UK creates.

133,000 tons of plastic annually with only 5% of it being recyclable [23] and hospitals in the USA produce more than 5 million tons of waste each year, 1.25 million tons of which is plastic. About 16 billion injections are utilized worldwide every year, but not all of them are properly disposed of afterward generating a huge amount of nonbiodegradable waste [24].

HCW that contains chemicals like pharmaceuticals, laboratory and diagnostic reagents, disinfectants, cleaners, solvents, and waste containing metals and heavy metals is considered chemical healthcare waste. Chemical waste accounts for about 3% of waste originating from health care activities [25].

The literature reveals even in small and economically not so sound countries like Pakistan hospitals produce 2.0 kg of waste, per bed per day, of which at least 0.5 kg can be categorized as hazardous HCW and the average daily HCWG from both public & private sector hospitals is approx 0.8 million tons [26].

## 7. COVID and HCWG

In 2019, an unprecedented medical emergency in the form of the COVID-19 pandemic was experienced by the whole world. The infection spread to the majority of areas and more than 370 million confirmed cases and over 5.6 million deaths have been reported globally. Tens of thousands of tons of extra HCW have been produced due to the medical efforts to treat and deal with COVID-19. The WHO Global analysis of HCW in the context of COVID-19 states that approximately 87,000 tons of personal protective equipment (PPE) were distributed to various countries from March 2020 to November 2021. It also points out that over 140 million test kits, generating 2,600 tons of plastic non-infectious waste and 731,000 liters of chemical waste have been shipped to support countries. Globally more than 8 bn vaccine doses have been administered generating 144,000 tons of added HCW in the form of nonbiodegradable syringes, needles, and safety boxes. Approximately 129 bn masks and 65 bn gloves were utilized per month globally during the COVID-19 epidemic increasing the burden of HCW immensely [27]. Wuhan in China, which is considered as the starting point of the COVID-19 outbreak has to manage a rise of HCWG of 600% during that period. **Table 8** shows an increase in HCW during COVID-19 outbreak in some cities. In Taiwan, it is reported that HCW generation has increased to 40,407 Mt. in 2019from 35,747 Mt. in 2016, an increase of 4.17% in three years span [28].

In a highly populous country India, about 420,461 kg/day of HCW is generated out of which only 240,682 kg/day of waste is treated [29]. India generated 550.9 tons/day of HCW in 2020 as per the estimation of ASSOCHAM (Associated Chambers of Commerce and Industry of India).

## 8. Effect of HCW on Environment

The HCW affects all components of the environment. The effect on water, soil, and air is discussed below.

### 8.1 Impact of biomedical waste on water

HCW is a multi-component waste; improper disposal of HCW causes leaching out of pollutants from the waste dumping sites into the surrounding water bodies including groundwater affecting water quality. The water near landfills and dumping sites contain a relatively higher amount of pollutants including heavy metals [30–32] found that incinerated biomedical waste contains the elevated percentage of heavy metals and polycyclic aromatic hydrocarbons (PAHs), and may pollute surface and groundwater by percolation of toxic substances. The analysis of water near HCW ash showed increased hardness at the levels of 1320 mg/L and chloride at 8500 mg/L. The levels of Al, V, Cr, Mn, Co, Ni, Ba, Fe, and especially Pb content in leachate were above the acceptable levels as per drinking water guidelines of WHO and EPA. Hence, it is also important to detoxify ash before disposal into landfills or reutilization [33, 34]. They cause indirect health hazards by conversion into other materials, breakdown, and decomposition. Consumption of contaminated drinking water and the resulting health issues may include cardiovascular disorders, neuronal damage, renal injuries, and risk of cancer and diabetes. Fabián Fernández-Luqueño et al. has comprehensively revived the health hazards of various metal contaminants on human health [35] Water is considered as the blood of the ecosystem. Heavy metals are extremely toxic to aquatic animals and cause histopathological changes, especially in fish even at low concentrations. They get accumulated in aquatic organisms as well as in vegetables and fruits grown using contaminated water and thus enter the food chain and propagate into other animals who feed on them thus increasing toxic effects to many folds [36].

### 8.2 Impact of biomedical waste on soil

Soil quality near waste dumping sites is greatly affected by improper and unscientific disposal of HCW, resulting in alteration of physical and chemical soil properties. The chemistry and biology of the soil ecosystem may change due to different pollutants getting mixed with the soil. The soil samples near the HCW incinerator and dumping sites were found to have very high concentrations of heavy metals like Fe, Cu, Zn, Cr, Cd, Pb, and Ni [37–40]. Soils at these sites showed high pH, TDS, and EC regime in comparison to control sites resulting in deteriorating soil quality and a decrease in vegetation [41]. The study in china indicated that the HW ashes contained large amounts of metal salts of various common metals with a concentration range of 1.8–315 g /kg. Abundant precautions and measures are needed to further prevent and reduce soil damage due to HCW with increased waste development due to increased establishment and utilization of healthcare facilities [42].

### 8.3 Biomedical waste and its impact on air quality

Greenhouse gas and particulate emissions are challenging issues for HCW dumping sites. Hospitals produce a huge quantity of waste mostly disposed of by incineration. Incineration is the conventional and most common method of choice for the treatment of HCW. The burning of HCW pollutes the environment by discharging fly ash and toxic metals in the incinerated ash. Burning HCW results in higher incidences of cancer, respiratory disorders, innate abnormalities, and hormonal disorders other issues related to the burning of HCW are contribution to global warming, acidification, ozone or smog formation, and eutrophication. This also releases various gases

and particulate materials into the air contaminating the environmental air. Dust, particulate matter, black carbon, metals, acid gases, ammonia, sulfate, and nitrate are the major contaminants released in the air. Burning of HCW emits harmful organic compounds like acetone, octane, decane, dodecane, methenamine, cyclo-butane, diethyl phthalate, nonane, carbon disulfide, and diperoxide [43]. The incineration of plastic-rich hospital waste results in emissions of HCl, CO, $C_2H_4$, $C_2H_6$, $C_3H_8$,$C_3H_6$ in the concentrations of 3.3–5.3, 1.4–1.8, <0.002, <0.010, <0.012, and < 0.011 g/kg, respectively [44]. A high concentration of dioxin and furan in the atmosphere near medical waste incinerators was reported [45]. The high prevalence of self-reported

| S. no. | Heavy metal contaminant | Toxicity |
|---|---|---|
| 1 | Mercury (Hg) | CNS injuries |
| | | Renal dysfunction |
| | | Gastrointestinal ulceration |
| | | Hepatotoxicity |
| 2 | Lead (Pb) | CNS injury |
| | | Lungs dysfunction |
| | | Hematological disorders like anemia |
| | | gastrointestinal colic |
| | | Liver damage |
| | | Reduced pulmonary function |
| | | Cardiovascular dysfunction |
| 3 | Chromium (Cr) | Kidney dysfunction |
| | | Gastro intestinal disorders |
| | | Dermal diseases |
| | | Increasing the incidence of cancers including lungs, larynx, bladder, kidneys, testicular, bone, and thyroid |
| | | Genomic instability |
| 4 | Cadmium (Cd) | Degenerative bone disease |
| | | Renal dysfunction |
| | | Liver disorder |
| | | GI disorders |
| | | Lungs injuries |
| | | Disorders in the metabolism of metals like Zn and Cu |
| | | Cancer |
| 5 | Arsenic (As) | Cardiovascular dysfunction |
| | | Skin and hair changes |
| | | CNS injury |
| | | Gastrointestinal discomfort |
| | | Liver damage |

**Table 11.**
*Health hazards of heavy metal contaminants in HCW [52].*

health symptoms such as fatigue, sleepiness, and headaches among residents near waste sites was reported in most of the studies [46–48]. The process of incineration may convert solid and liquid toxic waste into gaseous emissions, particulate matters, oxides of nitrogen, and oxides of sulfur causing acute effects such as eyes and respiratory irritation. It also increases the toxic effects of heavy metals and contributes to acid rain. The plastic waste made up of chlorine releases dioxins that are known as human carcinogens [46].

The increased level of these pollutants is dangerous to human health causing various types of health issues especially respiratory problems [49]. Studies have also reported the prevalence of adverse health effects other than respiratory problems like birth defects with low birth weight, cancers, etc. in individuals residing near HCW processing and dumping sites [50]. The study findings suggest a relatively higher prevalence of various health issues among people living in proximity to waste dumping and processing sites than those living far from these sites particularly respiratory illness (23% v 10%), eye irritation (20% v 9.5%) and stomach problem (27% v 20%) [51–53].

Heavy metals generate reactive oxygenic species (ROS) and induce oxidative stress which is responsible for various diseases and health conditions. Acting as metabolic poisons they react and inhibit sulfhydryl (SH) enzyme systems which are involved in cellular energy production. Heavy metals have been reported to be carcinogenic, mutagenic, and teratogenic [54]. The harmful effects of heavy metals which are the main pollutants from HCW are depicted in **Table 11**.

## 9. Management of nonbiodegradable wastes

Management of waste involves steps right from the generation to disposal of the treated waste. For nonbiodegradable waste, special care has to be taken during collection, storage, transport, and disposal. All are separated from general biodegradable and nonhazardous waste.

As nonbiodegradable wastes cannot be broken down by decomposers, their disposal poses a grave problem. Nonbiodegradable wastes can be managed by practicing the principle of **4RD**s i.e. Reduce, Reuse, Recycle, Recover, and Dispose. The fifth R i.e. Refuse is also very important in controlling HCW.

### 9.1 Reduce

The best mode to control pollution is reducing the release of pollutants in the environment, which can be achieved by reducing the usage of polluting materials. Without giving a thought, often more things are utilized than are actually needed resulting in the generation of more quantum of waste. The generation of waste needs to be reduced by reducing the usage of nonbiodegradable waste generating materials. Consume maximum and throw away minimum should be the guiding principle in the selection and utilization of materials in general and nonbiodegradable materials in specific. Thoughtful planning for use of nonbiodegradable materials for minimum waste generation should be the priority of all healthcare activities.

### 9.2 Reuse

Increased use of the single-use materials leads to increased generation of waste. Hospitals should try to make it a practice to utilize reusable materials

wherever possible. Certain things can be used for more than one purpose and if we reuse them for the same or other purposes, we can reduce the waste generation. This can be employed not only for nonclinical use like eatery and other nonclinical purposes use but also for clinical uses wherever possible. Use glass or metal containers and trays which can be cleaned and even sterilized after every use. Also use cloth gowns and masks instead of plastic protective units in areas where they can be used.

### 9.3 Recycle

The process by which waste materials are utilized in the production/creation of new products is called recycling. The materials used/reused in recycling are substitutes for raw materials obtained from natural resources thus reducing the exploitation of natural recourses to some extent and also reducing contamination of the environment by waste disposal. It also prevents wasting potentially useful materials and reduces demand for new raw materials. Generally, materials like glass, metal, plastic, wood and paper are collected, separated, and recycled to make new things. The energy generation from waste treatment is also a part of the recycling process. Recycling can be internal (in-house) or external.

Following steps can be undertaken for nonbiodegradable waste management.

- Setting up nonbiodegradable waste collection centers in specific wards or divisions where the waste is temporarily stored before further processing.
- Segregation of waste into BW and NBW.
- NBW is taken for a separate treatment process.
- Transport with care to avoid spillage.

### 9.4 Recycling of nonbiodegradable waste

In the case of nonbiodegradable wastes, in addition to the 3 Rs of managing waste, a 4th R of Refuse should be considered. So, Refuse, Reduce, Reuse and Recycle, and Dispose is the best policy for reducing nonbiodegradable waste.

The nonbiodegradable waste goes for processing and treatment at specific waste treatment plants where they are recycled. Usually, the treatment of nonbiodegradable waste is done on the basis of the nature of the material it is made up of. Different procedures employed according to the major types of recycled waste are.

**Iron metal materials:** Iron is the most recycled metal. Recycled by separating by magnetic methods, melting in a furnace, and used for the production of other iron materials or steel.

**Non-iron metal materials:** Other metals like aluminum, copper, and alloys like brass are ground into fine pieces and molten to be recast in new materials.

**Glass:** Glass is crushed, decolorized, and put into the furnace for melting. This can be remolded into other articles of required shape and size. Molten glass is also used for layering on roads as glassphalt.

**Plastic:** Plastics are of various types and grades that all cannot be mixed together for treatment and need to be sorted. The plastics can be further processed remolded and used for making new materials.

## 9.5 Recover

Every material requires and intakes a lot of energy during its manufacture and the energy in waste materials cannot be wasted. It is cost-saving and eco-friendly to recover energy from waste materials.

Energy from biodegradable waste can be extracted relatively easily and efficiently by biomass energy conversion, composting, biogas plants, etc. This process converts biological energy into a usable form of energy like gas and electricity [55].

Energy retrieval from nonbiodegradable is somewhat difficult and requires a complex process. NBW is subjected to a process of thermal decomposition or pyrolysis, which involves the breaking of intermolecular bonds to release energy in the form of heat. The residue obtained is in the form of ash or degraded product which can be safely dumped or discarded.

## 9.6 Dispose

### *9.6.1 Ways to dispose of nonbiodegradable waste*

Not all waste fits into the criteria of reuse or recycle. These waste needs to be disposed off in a way to have minimal impact on the environment. Disposal of biodegradable waste is very simple and can be done employing easy methods like landfilling, composting, etc.

The NBW cannot be decomposed naturally and need special disposal techniques for minimizing hazardous effects on environments and people handling it. Let us look at some nonbiodegradable waste management methods commonly used.

### *9.6.2 Incineration*

Usually used for nonrecyclable nonbiodegradable waste and bio-hazardous waste from hospitals, etc. Incineration involves decomposition by combustion of waste using high heat, i.e. above 500°C. It is also referred to as the thermal treatment of waste. Incineration of waste converts it primarily into ash, flue gas, and heat. Heat can be used for various heat-based processes. The gases and fumes must be treated properly to prevent or at least reduce environmental pollution. Air filters are nowadays employed for the same. Modern methods of incineration such as gasification, pyrolysis, and anaerobic digestion can be utilized for energy recovery. Useful content from the residual ash contains metals that can be recovered using separate treatments. **Table 10** depicts some methods of incineration for waste disposal (**Table 12**).

Incinerators reduce the mass of the waste by 80–85% and the volume by 95–96%, depending on the composition and degree of recovery of materials such as metals from the ash for recycling [53].

### *9.6.3 Landfills*

Solid waste landfill is a separate area of land or excavation where waste is collected. It provides long-term storage for nonbiodegradable waste. Ideally, landfills should be carefully situated and designed to prevent waste contamination from entering the neighboring environment. They are designed to reduce odor and pests to the maximum possible extent.

| S. no. | Type of Incineration | Features | Concerns |
|---|---|---|---|
| 1 | Burn pile | Carried out in the open ground. A mound of combustible waste materials is piled on and set on fire. | Cause pollution.<br>Spread uncontrolled fires.<br>Incomplete combustion of waste produces particulate pollution. |
| 2 | Burn barrel | It holds the burning waste material inside a metal barrel having a metal grating over the exhaust. The spread of burning material is prevented by the barrel and residue after processing settles down in the barrel. | Cause pollution.<br>Do not result in full combustion of waste and therefore produce particulate pollution. |
| 3 | Fixed grate | Simplest and most common form. It has a brick-lined chamber and a fixed metal grate over a lower ash pit. There are two openings, one either at the top or side for loading waste and another on the side for removing residue. | Cause pollution.<br>The combustion is partial.<br>Do not result in full combustion of waste and therefore produce particulate pollution. |
| 4 | Moving grate | Consists of an opening called "throat" for feeding waste at one end of the grate. The waste burns and moves through the descending grate to the ash pit present at the other end and is removed through a water lock. | Complete combustion.<br>Advanced designs cause reduced pollution and can be utilized for energy generation. |
| 5 | Rotary-kiln | Contains a primary chamber and secondary chamber. The primary chamber has an inclined refractory lined cylindrical tube where volatilization, destructive distillation, and partial combustion reactions convert waste into gases that are completely burned in the secondary chamber. | Complete combustion<br>Cause pollution.<br>Prone to the production of gas and particulate pollution though can burn in afterburner. |
| 6 | Fluidized bed | It consists of a waste processing chamber where a strong airflow is forced through a sand bed until a fluidized bed is created. At this point the fuel and waste are introduced, mixing and churning occurs, and waste is incinerated. As the bed is mixed and agitated with force, content forms a fluid-like state making all of the mass of waste, fuel, and sand fully circulating through the furnace for efficient incineration. | Complete combustion<br>Highly efficient process<br>Can cause pollution if generated gases and ash not properly managed |
| 7 | Specialized incinerator | These are designed for incineration of special waste content lime chemicals, resin powder, and flammable substances. The process has higher control and prevents burn back. | Complete and controlled combustion<br>Can handle critical waste components.<br>Generated gases and ash need to be properly managed. |
| 8 | Liquid injection incinerator | It has a waste burner feed system, a supporting fuel system, and an air supply system attached to the combustion chamber for maximum incineration. | Used for waste in liquid form.<br>Complete combustion.<br>Cause pollution.<br>Can be used to recover metals and energy. |
| 9 | Multiple hearth incinerator | Consist of a number of circular hearths or kilns superimposed over each other. Waste is introduced from the top and moved by rotating "rabble arms", which move over the surface of each hearth to continuously shift the content. | Complete combustion.<br>High flexibility and efficiency.<br>Precise control of the temperature profile.<br>Less pollution. |

| S. no. | Type of Incineration | Features | Concerns |
|---|---|---|---|
| 10 | Catalytic combustion | It is a chemical process in which a catalyst is used to speed up desired oxidation reactions and reduce the formation of undesired products. | Complete combustion.<br>High flexibility and efficiency.<br>Precise control of the temperature profile.<br>Less pollution especially nitrogen oxide gases (NOx). |

**Table 12.**
*Methods of incineration for waste disposal.*

Sanitary landfills are similar to normal landfills but are built in a planned and methodical way. Normal landfills cannot completely prevent the leaching or leakage of waste and toxic substances along with water into the ground. Sanitary landfills are closed areas built with concrete and with facilities to collect the leachate and gases released. These also are superior in preventing pest breeding and pathogen spread.

Large area requirements, cost and chances of leakage, and pollution are some disadvantages.

### *9.6.4 Plasma arc furnaces*

They are referred to as "plasma recycling," and "plasma gasification. In this process, the waste is heated to super-high temperatures where it melts and then vaporizes producing gas that can be used for energy and rocky solid residue that can be used for various purposes like a building material. Unlike inclinators which convert waste to ash and gases, plasma arc furnaces first directly convert waste to plasma, the fourth state of matter, and then produce gasification. Thus, it's a cleaner, greener form of waste treatment.

### *9.6.5 Encapsulation*

Encapsulation is covering of material with some kind of material uniformly resulting in a product called the capsule. In waste disposal by encapsulation method, the waste is crammed very compactly in an inert cover just like a capsule which does not allow any exchange of materials including gases. These capsules of waste are buried deep down into the ground resulting in safe and long-lasting waste disposal without any leakage, leaching, and contamination of the environment.

At the COP26, world leaders discussed strategies directly affecting climate change. The Centre for Sustainable Healthcare has requested world leaders to take initiatives to make sure that healthcare systems are Net Zero by 2040. They further stated to fund existing healthcare facilities to transfer them to environmentally sustainable healthcare systems. This includes collaboration with all players in the supply chain to de-carbonize medical devices. Reducing plastic medical waste is an essential strategy.

## 9.7 Refuse

It is the fifth "R" of waste management. Refuse should be the first choice which involves refusing a certain amount of waste production. Refuse means not using or

| | |
|---|---|
| REFUSE | The concept is about refusing the use of materials that add on to the nonbiodegradable waste burden. If we refuse to use them and stop buying these materials in the first place, then automatically we will not have to deal with them as waste. |
| RETHINK | Thinking about any material we use and try to adopt a Zero Waste practice thus rethinking the way we carry out hospital services so as to minimize waste generation. |
| REDUCE | Reducing unnecessary waste generation by using fewer materials should be a priority and adopted policy from the start. Also reducing energy consumption can indirectly help in reducing environmental pollution. |
| REUSE | Reusing any material, which can otherwise be a waste results in reduced waste generation. Applying some creative thinking and processing can result in the consumption of new materials and waste generation. |
| RECYCLE | Recycling all the waste to create new materials or products can reduce environmental hazards to a great extent. Using recycled products wherever available and possible can also serve the purpose to great extent. |
| RECOVER | The recovery of waste is of two types processed and without any pre-processing. Waste oils can be burnt for energy or energy can be recovered by processing waste with novel techniques to generate energy and thus reducing dependence on nonrenewable energy sources to some extent. |
| REPAIR | Repairing means fixing or restoring supposed to be waste material for use or reuse. This should be applied wherever possible instead of just discarding damaged materials /items as waste. |
| REPURPOSE | Repurposing comprises of using items for a different purpose than they were meant for. This is also termed as up-cycling Utilizing waste material for another use instead of disposing of it ending in hazardous waste. Some products can be repurposed using creativity and the possibilities are endless. |
| DISPOSE | The process of getting rid of HCW by one or other way like landfilling or incineration when all of the above means are exhausted. This should also be done scientifically and very carefully to have minimum effect on the environment and health. |

**Table 13.**
*Strategies for HCW management.*

discontinuing use of waste-generating things, especially nonbiodegradable and hazardous things. Refuse can act as the most prominent measure in reducing waste generation. By refusing the usage of certain materials, one can avert the HCW generation thus not requiring any treatment or processing and saving a lot of financial resources, and preventing health and environmental hazards waste. For example, the refusal to single-use plastic in HCI will not only decrease the amount of plastic in HCW but will also prevent the related effects of plastic waste. It can look impractical and difficult, but there are some better and less waste generating options that can be opted for. It's the most effective way to reduce the amount of waste HCI is producing.

The measures are summarized in **Table 13** with enlisting more R's.

## 10. Causes for failure of waste management efforts

### 10.1 Lack of awareness about the hazards related to healthcare waste

Not only the general public but even highly educated people including healthcare professionals are not fully aware of the hazardous effects of HCW on health and the environment. Due to this, the HCWM does not gather the importance needed

resulting in a casual and careless approach. Not all the hospital staffs have knowledge of standard protocol for collection, segregation, and disposal of HCW. In most of the cases, health care staff does not receive occupational safety education and has no knowledge of the safe handling of hazardous substances. They also are not properly trained for using personal protective equipment. A large number of waste handlers and cleaners are casual labors and are illiterate or relatively very less educated unvaccinated and untrained personnel. They generally never use proper personal protective equipment and do not understand the threats of HCW thus putting their and other's health in danger. HCW is transported by hand in regular waste risking spilling of toxic or infectious materials, or injuries to handlers from sharps like needles or other substances. Either, they are unaware or have very little knowledge and a careless approach towards safety measures like spillages and accidents. As the cleaners and waste handlers are in close contact with HCW, they are the worst sufferers of the effects of poor and improper safety procedures [56]. These factors lead to escalation of HCW which could be reduced if given needed importance and attention.

### 10.2 The low priority is given to the waste management

The HCW management requires the highest consideration and assiduousness to avoid the significant health challenges related with poor HCWM practices like exposure to infectious HCW and toxic material therein. It is one of the most prominent results of failure of HCWM. Sometimes even though the importance of safe management of HCW is sometimes known and understood but the efforts required are not undertaken.

It is generally regarded especially by the general public that waste management is the sole duty and responsibility of government and local administration and that the public is not supposed to contribute [57]. Waste management's success depends upon the active participation of all, the government through local administration, hospital management, and workers and patients. The guidelines related to waste management should be made mandatory to be followed by the hospital staff and regular monitoring of the same can lead to improved compliance. Hospital management is focused on earning more profit from the services without any regard for the environment and HCWM resulting in illegal and uncontrolled disposal of untreated waste increasing the severity of the problem.

The vital issue is the clear ascription of responsibility and accountability of apt handling and processing of HCW. According to the concept of "you pollute you clean or you pay", the responsibility of HCW management lies with the waste producer, the healthcare provider, or the establishment involved in related activities being the one. This needs to be made known to the healthcare system and fixing accountability with them can only bring some seriousness in their attitude.

### 10.3 Lack of legal framework and absence of waste management and disposal systems

Many countries either do not have proper regulations, have very nominal regulations, or do not enforce them strictly. Research indicates that having adequate legal framework results positively in the development of a waste management system [58] while the dearth of adequate policies [59] and not so strong regulations [60, 61] are disadvantageous to it. Lack of pollution and environmental control systems and systems for evaluation of the real impacts of pollution is a major concern, especially

in middle and lower middle-income countries. The developed countries have strong legislative frameworks and control systems which is lacking in developing and underdeveloped countries. In these countries/societies, the condition is relatively better in urban areas but practically missing in remote village areas [62]. Thus, there is no system of waste management and disposal and most of the waste including HCW remains dumped anywhere without treatment. If we consider a ban on disposable plastics it is somewhat functional in urban areas but completely nonexistent in rural areas where nonbiodegradable plastic enters but is never returned. The HCW is also treated as general waste most of the time and disposed off without due care and precautions.

### 10.4 Insufficient financial and human resources

The developing and underdeveloped countries are facing the problem of a dearth of financial resources to address the rising quantity of HCW resulting due to rapid urbanization and healthcare facilities. Lack of the proper utilization of available finances has hampered the delivery of proper waste management services [63]. The available resources are primarily allocated to the high-income urban areas with higher tax yields habituating residents with more political influence. This leads to vast area which is poor and suburban housing major population that is relatively economically weaker unnerved. Huge expenditure is needed to provide the service [64] inadequate and insufficient funds and resources local government cannot finance adequate levels of service required for waste management in general and HCWM in particular. In the absence of proper financial support, limited resources with reservations, and unwillingness of the users to pay for the waste management [65] contribute to the problem more.

### 10.5 Utilization of traditional ways instead of modern techniques

The technical issues hinder efficient and broader health care management. In most of places the conventional approach to deal with waste treatment especially health care waste is in practice. The modern techniques of collection, segregation, and processing are very expensive and adopted mostly only by developed and highly industrialized countries. These techniques are expensive to purchase and maintain, sophisticated, and difficult to operate, thereby often inadequate for the socioeconomic conditions of developing and underdeveloped countries to be used extensively. Even though if systems are procured and utilized after a short period of usage, usually only very few systems remain in operation for want of trained staff and maintenance cost. Other technical factors apart from insufficient technologies are lack of trained and technically skilled personnel within [66], poor infrastructure and roads, and old vehicles [67, 68]. There is a lack of validated and authenticated data systems making it unreliable to know the exact level of HCW generation, processing, and its effects [59].

Some key elements for improving healthcare waste management are

- Having a strong legal framework and guidelines.
- Spreading awareness towards risks associated with HCW and safe practices of its treatment and processing.

- Addressing responsibilities.
- Proper and sufficient resource allocation.
- Opting for safe and sound, environment-friendly HCW management options.
- Building a comprehensive system for handling, processing, and disposal.
- Protecting people from hazards when collecting, handling, storing, transporting, treating, or disposing of waste.
- Long-term planning for gradual and sustained improvements.
- Government commitment and support to local bodies and both public and private players involved in waste management.
- Incentives for best practices and performance.
- Universal cooperation and sharing of knowledge and technology.

## 11. Conclusions

The problem of HCW management in general and hazardous and nonbiodegradable portion thereof is too big to be ignored or else it will boomerang into something, which will be very difficult to manage. Though, at first sight, it does not look that severe a close analysis reveals that it is one of the major sources of greenhouse gas emission and comprehensively affects all the components of the environment and contributes to global warming. One of the serious aspects of HCW is its threat to the health of humans and animals as a good part of HCW contains infectious waste. The HCW contaminate the air, water, and soil of the surrounding environment releasing toxic substance like chemicals including heavy metals and radioactive substances, carcinogenic toxic gases like dioxin and furan, and causing many health issues not only in humans but also in animal species. The surrounding areas in dumping and processing sites are affected by these pollutants making them inhabitable. There is an urgent need for comprehensive research on the health hazards of HCW and measures to prevent them, processing of HCW and development of biomarkers for risk assessment of HCW, and a standard protocol for its processing that can be made mandatory to be followed by HCI. Unless there are universal consensus and framework for dealing with HCW the problem will not be solved. The healthcare industry needs to adopt eco-friendly approaches and operations and initiate whatever it takes to really become a health care provider and not itself become a threat to the health of living and nonliving environment by indiscriminate toxic HCW generation. Measures like extensive awareness and training programs, setting up environment-friendly hospitals, and avoiding single-use materials should be undertaken. Refuse, reduce, reuse, recycle, recover, and dispose should be the governing principles of HCW management. With collective responsibility, sincerity and honest efforts the menace of HCW in general and nonbiodegradable in specific can be not only controlled but contained for good of the environment in general and human health in specific.

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