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Solid Waste Management

Principles and Practice

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The authors dedicate the book to their families and colleagues

Preface

Ideally, a theory and a practice should be the same. However, when it comes to reality, theory differs from practice.

Every year nearly one-third of the world's population dies due to commucable diseases. On the other hand, many countries spend more than one-third of their annual expenditure on armed forces without realising that the threat to their community is more within the nation.

While most of solid waste management is designed by literates and experts, a major part of the solid waste is managed by illiterates or the least literate or non-expert. Hence, there will always be shadows between the aspiration and realty—the reason that many solid waste management projects fail. While international consultants prepare volumes of manifests for hazardous waste transportation, illiterate drivers ship hazardous wastes with these manifests without knowing what to do with them.

While international agencies fund many waste management projects, corrupt politicians may seek a share in the amount spent toward such a project. In addition, there is also an inherent culture of citizens in many developing countries throwing waste on the streets. While the third world struggles to get rid of waste from the immediate neighborhood, some developed countries may add to the waste by shipping waste from their countries in the name of charity or other guise.

Solid waste management needs more common sense rather than the solution of complicated partial differential equations and financial plans.

In spite of many lacunae, innumerable efforts have been made in the past few decades to do much for the Earth. Although waste management has not developed the way some other streams of science/engineering have grown, there are people and agencies who are working within their own limitations which have helped make progress in this area.

Once we dig out and use all the possible resources on the Earth we would definitely turn to waste for recovery of resources—a practice which is now proven to be profitable in the case of extracting precious materials from waste from electrical and electronic equipments rather than from the ore.

Considering the above issues, an attempt is being made by us to minimize the knowledge gap in print and on field after working more than a decade in the field and surveying more than 300 literatures. We have made an attempt to touch almost all the important aspects of solid waste in this book while keeping in mind both the theory and practice. We have also tried to bring wholesomeness to our effort by discussing problems across the world instead of sticking to a single country.

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Contents

Abbreviations

3R	Reduce, Recycle and Reuse
ABS	Australian Bureau of Statistics
ACM	Asbestose Containing Material
AD	Ano Dominy or Anaerobic Digestion
ADB	Asian Development Bank or African Development Bank
AFP	Active Fire Protection
AIDS	Acquired Immunodeficiency Syndrome
APO	Asian Productivity Organisation
ASR	Automotice Shredder Residue
BaO	Barium Oxide
BARC	Bhaba Atomic Research Centre
BBMP	Bruhat Bengaluru Mahanagara Palike (Metropolitan Corporation of Greater Bangalore)
BC	Before Crist
BF	Blast Furnace
BFS	Blast Furnace Slag
BMW	Biomedical Waste
BIS	Bio-Intelligence Services
C&D	Construction and Demolition
CaO	Calcium Oxide
CBA	Cost Benefit Analysis
CCl_4	Calcium Tetra Chloride
CEA	Cost Effectiveness Analysis
CFC	Chloro Flouro Carbon
CH_3COOH	Acetic Acid
CH_4	Methane
CHNS	Chorbon, Hydrogen, Nitrogen, Sulphur
Ci/Kg	Curie/kg
CIDA	Canadian International Development Agency
CNS	Central Nervous System

CO_2	Carbon Dioxide
CPHEEO	Central Public Health and Environmental Engineering Organisation of India
CRT	Cathode Ray Tube
CSIR	Council for Scientific and Industrial Research
CTC	Carbon Tetra Chloride
CWC	Clean Washingdon Centre
DCC	Dhaka City Cooperation
DMP	Disaster Management Plan
DRS	Deposit Refund System
DSNC	Department of Sanitation Newyok City
DTI	Department of Trade and Industry
DTI	Department of Trade and Industry of the UK
DW	Disaster Waste
EBS	Engineered Barrier System
ECDGE	European Commission Director General Environment
EDA	Emergency Declaration Area
EEA	European Environment Agency
EEE	Electrical and Electronic Equipment
EH&S	Environment Health and Safety
EIA	Environmental Impact Assessment
ELV	End of Life Vehicle
EMP	Environment Management Plan
EoL	End of Life
EPA	Environment Protection Agency of the USA
EPHA	Environmental Public Health Act
EPP	Emergency Preparedness Plan
EPR	Extended Producer Responsibility
EU	European Union
FHNW	University of Applied Sciences Northwestern Switzerland
FMD	Floating Marine Debris
FML	Flexible Membrane Liners
GCL	Geosynthetic Clay Liner
GDP	Gross Domestic Product
GESAMP	Group of Experts on the Scientific Aspects of Marine Pollution
GHG	Greenhouse Gases
GI	Gastro-Intestine
GPS	Global Positioning System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (German Technical Cooperation)
H_2O	Water
H_2S	Hydrogen Sulphide
HC	Hydrocarbons

HCl	Hydrogen Chloride
HHP	Household Hazardous Product
HHV	Human Herpesvirus
HHW	Household Hazardous Waste
HIV	Human Immunodeficiency Virus
HLS	School of Life Sciences
HLW	High-level Wastes
HOD	Handing Over Document
HSE	Health and Safety Executive of the UK
HSLT	High Speed Low Torque
IAD	Ion Assisted Deposition
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
IEC	Institute for Ecopreneurship
ILO	International Labour Organisation
ILW	Intermediate Level Waste
IMDG	International Marine Dangerous Goods
INS	In-situ Leach
IPCC	Intergovernmental Panel on Climate Change
ISL	In Situ Leach
ISWM	Integrated Solid Waste Management
IVD	Ion Vapour Deposition
IWB	Itinerant Waste Buyer
JICA	Japan International Cooperation Agency
K_2O	Potassium Oxide
L	Litre
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LDAR	Leak Detection and Repair
LDC	Less Developed Country
LFG	Land Fill Gas
LILW	Low and Intermediate Level Wastes
LILW-LL	Low and Intermediate Level Wastes-Long Lived
LILW-SL	Low and Intermediate Level Wastes-Short Lived
LLW	Low Level Waste
LSHT	Low Speed High Torque
LWD	Large Woody Debris
LWP	Limited Work Permit
mCi	Millicurie, 1/1000 of a curie
MCi	Megacurie, 1,000,000 times a curie
MEIP	Metropolitan Environmental Improvement Programme
MFA	Material Flow Analysis
MgO	Magesium Oxide

MoEKoC	Ministry of Environment, Kingdom of Cambodia
MRF	Material Recovery Facility
MRI	Magnetic Resonance Imaging
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
N_2O	Nitrous oxide
NA	Not Applicable
NaO	Sodium Oxide
NEERI	National Environmental Engineering Research Institute
NEP	Natural Edge Project
NFC	Nuclear Fuel Cycle
NGO	Non-governmental organisations
NH_4OH	Ammonium Hydroxide
Ni-Cd	Nickel-Cadmium
Ni-Cr	Nickle-Chroimum
NiMeH	Nickel Metal Hydride
NMRS	Nuclear Magnetic Resonance Spectrometer
NO_2	Nitrogen Dioxide
NORM	Naturally Occurring Radioactive Materials
NORM	Naturally Occurring Radioactive Waste
NOx	Oxides of nitrogen
NWM	Nuclear Waste Management
O_3	Ozone
°C	Degree Celcius
ODS	Ozone Depleting Substance
OECD	Organisation for Economic Co-operation and Development
OPC	Ordinary Portland Cement
OPCW	Organization for the Prohibition of Chemical Weapons
P&T	Partitioning and Transmutation
PBDE	Poly-Brominated Diphenyl Etters
PbO	Lead Oxide
PCDD/Fs	Polychlorinated Dioxins and Furans
PDF	Packaging Derived Fuels
PDR	Peoples Democratic Republic
PEF	Process Engineered Fuel
PFA	Pulverised Fly Ash
PFT	Permission To Test
PMF	Powder Metal Fuel
POHC	Principal Organic Hazardous Constituents
POST	Parliamentary Office of Science and Technology
PP	Polypropelene
PPE	Personal Protective Equipment
PPF	Paper and Plastic Fraction
PPF	Passive Fire Protection
PRC	Pneumatic Refuse Collection

PS	Polysterene
PTW	Permit To Work
Pu^{+3}	Plutonium (III)
Pu^{+4}	Plutonium (IV)
PVC	Poly Venyl Chloride
RA	Risk Assessment
RCT	Reinforced Concrete Trenches
RDF	Refuse derived fuel
RDW	Reactor Decommisioning Waste
REF	Recovered Fuel
RFID	Radio Frequency Identification
RSS	Royal Scientific Society
RTS	Reservoir Triggered Seismicity
SA	Sustainable Assessment
SBA	Sustainable Business Associate
SCN	Safety clearance Notice
SEA	Strategic Environmental Assessment
SHG	Self Help Group
SiO_2	Silicon dioxide
SLF	Substitute Liquid Fuel
SLT	Stone-Lined Earth Trenches
SMS	Steel Melting Shop
SNF	Spent Nuclear Fuel
SoEA	Socioeconomic Assessment
SOP	Standard Operating Procedure
SPW	Solid Petroleum Waste
SRS	Sealed Radioactive Sources
SST	Sea Surface Temperature
SWM	Solid Waste Management
TBBPA	Tetra Bromo Biphenol-A
TH	Tile Hole
TRU	Transuranic
TRUW	Transuranic Waste
TSDF	Treatment, Storage and Disposal Facility
TTD	Tirumala Tirupathi Devastanam
TWRF	Tsunami Waste Recovery Facilities
UC	Uropean Community
UK	United Kingdom
ULB	Urban Local Body
UN	United Nations
UNEP	United Nations Environment Protection Agency
UNU	United Nations University
USA	United States of America
USACE	U.S. Army Corps of Engineers
USEPA	United Stares Environment Protection Aency

USFA	United States Fire Administration
VFA	Volatile Fatty Acid
VLLW	Very Low Level Waste
VOC	Volatile Organic Compounds
VRF	Volume Reduction Factor
WEEE	Waste from Electical and Electroic Equipment
WTE	Waste to Energy
ZnO	Zinc Oxide

Chapter 1
Introduction

Solid waste was a problem even before water and air pollution issues attracted the notice of human civilisation. Problems associated with solid wastes can be dated back to prehistoric days. Due to the invention of new products, technologies and services, the quantity and quality of waste have changed over the years. Now, the waste characteristics depend not only on people's income, culture and geography but also on the economy a society undergoes and situations like disasters to which the society may be subjected to.

The twentieth century is recognised as the *American Century* and the twenty-first century is recognised as the *Asian Century* and, it seems everybody wants to earn 'as much as possible' (Ramesha et al. 2011). After Asia the developing Africa could take the central stage of development in the coming years. Development does not come without environmental burdens and generation of waste is one among them. Waste in recent times has become a topic of extensive attention in academic and popular literature (Tim 2009). Waste is conventionally defined as unwanted material at the point of generation which does not have immediate use. Problems due to waste exist where there is a human inhabitants (UNEP 2004). As the name suggests, the term *solid waste* is used for waste which is solid. When governments took the responsibility of solid waste management originally, they bothered only about the waste generated from household and commercial activities. However, anthropogenic activities produce waste materials that are frequently discarded as they are considered useless. Some of the wastes are usually solid, and they are considered as useless and unwanted. But many of these waste substances can be reused and can be a resource for an industry. Indeed waste management is one of the most important problems of our time as development and subsequent use of materials generates enormous quantity of wastes.

In recent years many countries have passed laws with respect to municipal solid waste (MSW) management making urban local bodies (ULB) the obligatory organisation to manage solid waste. In many places the services of ULBs are poor

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in terms of efficiency and satisfaction ending up in problems of health and environmental degradation of the solid waste.

Under the Environmental Public Health Act (EPHA) passed in 1968 in Singapore, ‘‘waste’’ includes:

(a) *Any substance which constitutes a scrap material or an effluent or other unwanted surplus substance arising from the application of any process*; *and*
(b) *Any substance or article which requires to be disposed of as being broken*, *worn out*, *contaminated or otherwise spoiled*, *and*
(c) *Anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the contrary is proved.*

“Municipal solid waste” is a term usually applied to a collection of wastes produced in urban areas. The US Environmental Protection Agency (US EPA) (2008) defines *municipal solid waste* as:

> the materials traditionally managed by municipalities, whether by burning, burying, recycling, or composting.

As per the Municipal Solid Wastes (Management and Handling) Rules, 1999, in India:

> “municipal solid waste”includes commercial and residential wastes generated in a municipal or notified areas in either solid or semi-solid form excluding industrial hazardous wastes but including treated biomedical wastes;

The quantities and characteristics of waste generated in any region are functions of the lifestyle and living standards of the region’s citizens and the type of the region’s natural resources. Excessive quantities of waste are generated from a society from inefficient production processes, and low durability of goods as well as unsustainable consumption of resources (Nicholas 2003). Due to the varying degrees of development in different countries, it is difficult to generalise or standardise solid waste management as in corporate sector. Solid waste management involves understanding of existing waste management practice as well as adoption of new methods to overcome existing practices. While higher income regions have been known for ‘use and throw’ habit generating huge quantity of waste. Lower income regions use and reuse the resources available to maximum extent and hence generate lower quantity of waste. Other factors contributing to varying waste quantities and qualities are climate, economy, frequency of disaster, mindset of the people, and any others.

Ditches, where solid wastes are collected, were the main reason for epidemics in Europe in 1348 and 1665 (Alice 2008) which can be observed in developing countries now (Fig. 1.1). In order to overcome epidemics England passed an order in 1578 to eradicate plague compelling householder with a pump or a well to pour water down the gutters in the street and householders were required to sweep the mud/filth of the street and out of the gutters. As shown in Fig. 1.2 people even throw waste into unused wells poisoning the groundwater.

Fig. 1.1 Solid waste dumped in an open drain

Fig. 1.2 Water contamination of groundwater due to indiscriminate throwing of solid waste into a well

In developed countries wastes are generally carefully regulated and tracked through well developed record-keeping systems. But a developing country may not have sufficient people and resource to carry out a detailed record keeping. In spite of the good knowledge of constraints developing countries also make legislation in line with that of developed countries and sometime the legislations may be just copies of existing legislation elsewhere.

Lack of clear definition, roles, responsibility, and quality data has made the treatment and disposal problematic in developing world. Copying solid waste disposal models of developed countries like hauling to disposal site and land filling is leading to expenditure on transportation mostly by outsourcing to private agencies. The alternative model like segregation in yard nearer to point of generation is often discouraged to make business opportunity to waste transporting agencies.

1.1 Need for Solid Waste Management

The expenses for environmental management are multi-tiered, and future events are difficult to forecast with assurance. However, the risks in the future and associated costs can be minimized and eliminated by choosing appropriate preventive measures (Nicholas 2003).

Environment and human health can be affected by poor solid waste management. Over the years, solid waste management responses have been practiced all over the world like policies, regulation, and financial practices. The human population is likely to double between 1990 and 2015 with most of the growth occurring in less developed countries (LDC) and with the increased population there would be an increase in demand for efficient waste management practices. Waste is diverse in its origin and variety resulting in diverse impacts. The rapid change in technologies has resulted in dimensions of impact. The waste dumping in deserts, forests, streams, lakes, oceans, and other place has resulted in wide impacts leading to international and national legislations.

The needs for solid waste management are many. While it is sometimes carried for resource recovery, in other cases it could overcome problem of epidemic. Sometimes, it is carried out to avoid accumulation of hazardous substances which could lead to fire hazards. At other time it is carried out to avoid rodents and vectors. Irrespective of the reasons and methods it aims to restore the environment in which the inhabitants are comfortable.

With rising people, wealth and urbanization, it is a chief challenge for many nations to manage increasing quantity of solid waste. It must be further highlighted that reduction in Green House Gas (GHG), improved public health, safety and environmental benefits accrue from good waste management practices.

Figure 1.3 shows the impacts due to improper solid waste management. In a nutshell improper solid waste management has following impacts: (a) water and air pollution, (b) problems associated with bad odour, pests, rodents and stray animals, (c) generation of GHGs, (d) problems associated with aviation due to birds flying above dump site, (e) fires within the waste dump/land fill, and (f) erosion and stability problems in waste dump or land fill.

Historically, science and technology are based on new ideas, concepts, and their applications but in the past little emphasis is given on end of life cycle of the product and service. The term life cycle refers to period of product or service in society, and then death. Production of same product by different methods can have different impacts. For example foundry activity can be done either in cupola or induction furnace. The former generate large amount of air pollution and waste compared to induction furnace. Similarly sports activity in night will have more impact on environment as there is huge energy consumption in night compared to day. The packed food always generates more waste during manufacturing, transportation and use.

One way of reducing waste is to lower consumption and another way is to use clean technology. Poor countries adopt ‘dirty technology’ keeping their inability to

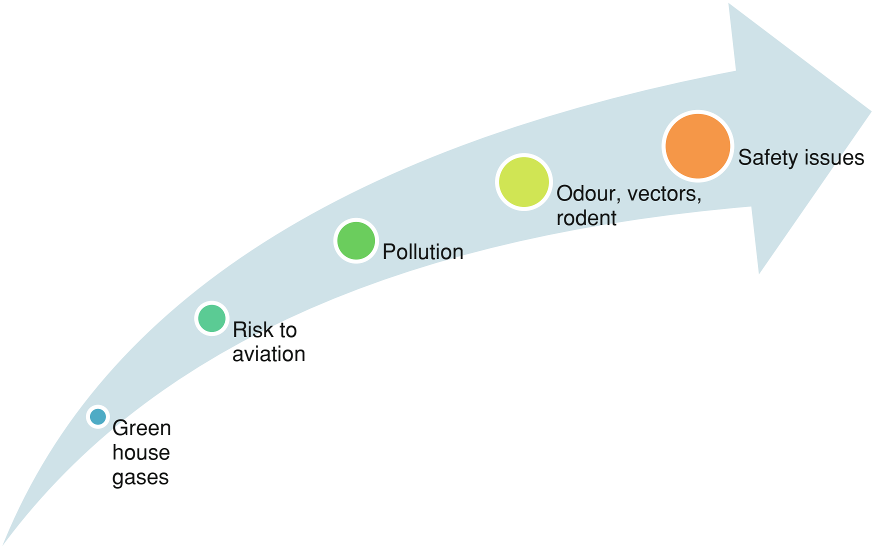


Fig. 1.3 Impacts due to improper solid waste management

spend towards cleaner technology. Whereas the rich countries adopt 'clean technology' but use a lot of packaging. As a result there is huge imbalance in the resource consumption and waste generation among various nations.

1.2 Importance of a Sound Solid Waste Management

In the developing nations, waste management regularly emerges as a problem which endangers public health and the environment. Waste management in developing countries seems to have a low priority as they are more bothered about issues like hunger, health, water, unemployment and civil war. Hence millions of people in the developing countries are living without an appropriate waste management system. In these countries uncontrolled waste dump is a huge danger for the environment and population due to contamination of the water and soil.

The organic fraction the waste not only attracts rodents and vectors, it also forms foul odours as well as unsightliness. Uncontrolled or inefficiently managed waste can contaminate water, air and soil. Many workers who handle waste and individuals who live near or on disposal area are infected with worms, gastrointestinal parasites and other related organisms (Cal Recovery Systems 1982). Sound waste management not only reduces the risk of commutable diseases, it also reduces toxicity of food and water due to entry of heavy metals and other chemicals. Solid waste management would also reduce resource depletion due to unnecessary mining, energy consumption and pollution problems during

Fig. 1.4 Bulky waste

manufacturing of new product. Proper recycling or reusing would add conservation of species due to unnecessary clearing forest and vegetation above the mineral resources.

Improper waste would also suffocate many species due to entry of material like plastic covers into food chain. The entry of toxins into food would also mean damage to ecology. The combustion in dump yards and other places not only add to pollution it will also add to GHGs. The loss of manpower due to acquired sickness due to improper waste disposal is difficult to estimate.

As would be discussed in subsequent chapters, the proper management would improve safety of waste handlers as well as general public. Proper solid waste management would also add revenue to local body by reducing unnecessary expenditure.

Population explosion and economic growth have resulted in increasing quantities of solid waste in urban areas. In most poor countries, the increasing quantities of waste have beleaguered local governments' ability to cope efficiently. In many of the developing countries, infectious wastes and toxic wastes are not segregated from other waste exposing the waste collectors to a variety of risks.

The solid waste is not always uniform throughout the year. It often changes from place to place and time to time. Figure 1.4 shows bulky waste generated during road widening which cannot be hauled by the truck which collects solid waste from streets and households. The uprooted trunk needs special cranes or it has to be made into pieces at the uprooted point. In either the case waste can be used as resource by using wood for furniture or for construction. Figure 1.5 shows art created by using waste from End of Life Vehicle (ELV)s. Such practices add not only to the efficiency of waste management process but also the economy of the country.

Another example for variation in waste quantity in the span of a year is shedding of leaves in spring which contribute to dry leaves. The festivals would

Fig. 1.5 Waste transformed into an art form

often generate greater amount of waste in markets and shopping areas. Riots and disasters would not only disrupt rhythm of solid waste management, they also add to new type of waste to the existing waste stream. The boom and recession cycles of economy would also affect the waste management by changing the type and quantity of waste.

In an attempt to speed up the industrial development, developing country may fail to manage solid waste. Such a failure invites a stern consequence afterwards in the form impact on the environment, public health and safety.

The indiscriminate disposal of waste is just not restricted to land or water. It may sometime stick to trees as shown in Fig. 1.6 affecting the aesthetics of the area and health of the tree.

Waste disposal can also lead to accident and traffic disruption as shown in Fig. 1.7 wherein the people have thrown the waste at the centre of the road as the civic authority have failed to place proper collection system in place. This picture which was taken from a lower income residential area in Delhi, India, is mainly due to the location of shops/houses very close to kerb side. In order to keep their premises clean the waste generators throw waste as far as possible from their property.

It is also interesting to know that pilgrimage centres and holy places will have unique situations calling for tailor made solution for the situations. Tirumala

Fig. 1.6 Waste on a tree

Fig. 1.7 Waste at the middle of a road

tirupathi devastanam (TTD) netted an income of 1,130 million rupees through 'e-auctioning' of human hair in the year 2011. Approximately ten million people shave their hair as an offer to deity, Lord Venkateshwara, in accomplishment of their prayers every year (Shukla 2011).

Another interesting situation wherein the data about waste generation is not available and secrete is from armed forces of all countries. Worldwide arms sale totalled 40.4 billion in the year 2010 (Thom 2011). It is not known how much the waste weapons and bullet are generated while testing and practicing usage of weapons are disposed off.

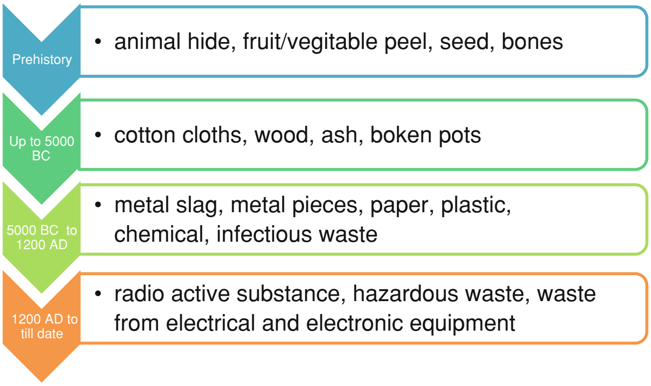


Fig. 1.8 Addition of new waste components over time

1.3 Change in Characteristics in Quantity and Time

Archaeological studies have shown layers from periods of prosperity and waste generation rates can be correlated to many indicators of prosperity (Bingemer and Crutzen 1987; Bogner and Matthews 2003; Mertins et al. 1999; OECD 2004; IPCC 2000; Richards 1989; Rathje et al. 1992a; US EPA 1999).

The plague, cholera and typhoid influenced monarchies and changed the populations of Europe. Europeans used to throw their domestic waste out of the window to the street through window and some still do so in the developing world. Figure 1.8 shows new components added to waste stream over the time. With innovation and development in science new products and business was added to the world. As a result the characteristics of waste changed from purely organic waste in prehistoric time to waste with radioactivity as on date.

Solid-waste generation rates depend on affluence and population, but data are questionable or deficient for many nations. Using data from 1975 to 1995, Bogner and Matthews (2003) developed models for per capita waste generation for developed and developing nations. As per Bogner et al. (2007) approximately 900 million tons of waste was generated globally in 2002 and Monni et al. (2006), indicated about 1250 million tons of waste generation in 2000 globally.

Per capita product and packaging waste increased by two folds between 1960 and 2005 while the per capita generation of food scraps and yard trimmings remained moderately constant in the USA (Sheehan and Spiegelman 2010). The quantity of metals in municipal solid waste of the USA changed from 12.3 % in 1960 to 7.7 % in 1996, whereas fraction of plastics changed from 0.4 % in 1960, to 9.4 % in 1996. Further, garden wastes declined from 22.7 % in 1960 to 13.4 % in 1996 (Franklin Associates 1998).

1.4 Waste Management in Pre-Industrialization Era

The history of solid waste is intricately bound with the history of civilisation given its omnipresent nature and visibility. For the last two million years humans generated little [please check] solid waste. The rate of garbage accumulated in the ancient city of Troy was estimated to be 1.4 million tons per century (Rathje 1990). The Roman practice of dumping solid waste in the streets caused considerable quantities of waste to be carried along the rainwater runoff.

Waste generated in pre-industrialization era was less toxic, low in quantity and easily biodegradable. The waste management prior to industrialization could be explained as below:

Human beings might have begun wearing clothing between 100,000 and 500,000 years ago. The people of the Indus Valley Civilization used clothing of cotton (which is now major component in urban solid waste) between fifth millennium BC and fourth millennium BC. Mohenjo-Daro city in the Indus valley had houses with rubbish chutes and Harappa City had toilets (Melosi 1981). With civilization, solid waste became an important issue. Human population of the world changed from one million in the year 10000 BC to 5 million in the year 5000 BC. Waste dumps were established away from settlements around 8000–9000 BC to avoid wild animals, insects, and odours (Bilitewski et al. 1997). The Minoans (lived around 3000–1000 BC) covered waste with layers of soil (Priestley 1968; Wilson 1977). By 2100 BC cities on the island of Crete had trunk sewers (Melosi 1981; Vesilind et al. 2002). The Neolithic revolution was the initial point for the transition from nomadic communities to settlement. During this period, the concept of solid waste management was not evolved. Waste removal was done randomly at convenience individuals could dump waste wherever they felt like dumping.

Very few records exist related to solid waste management prior to 3000 BC (Matthew 2009). The first documentation of solid waste management occurred in Athens, Greece during 500 BC and the city of Athens structured the first municipal dump where people were required to dispose the solid waste at least one mile away from city walls (Matthew 2009). The cities on the island of Crete had trunk sewers connecting homes in 2100 BC (Melosi 1981). In the Egyptian city of Heracleopolis (founded about 2100 BC), the wastes from “non-elite” section were ignored and waste from elite and religious sections were collected and disposed (Melosi 1981).

Metallurgy evolved between fifth and sixth millennium BC, and making of alloy began around 3500 BC during the Bronze Age. Around 1200 BC, the world witnessed the beginning of the Iron Age. Metallurgy brought with them an array of slag and scrap materials.

Archaeological studies reveal municipal dump in Athens Greece (Wikipedia 2011) during 500 BC. Municipal dump is established in ancient Athens (bfi-salinas 2011) during 400 BC. The first landfill was commissioned in Knossos Crete during 3000 BC (Ace disposal 2011; Matthew 2009). In the fifth century BC Greek

Fig. 1.9 Paper which forms more than 15 % of today's municipals solid waste in many parts of the world was invented in China during 2nd century BC

municipalities started to establish town dumps for garbage consisted of food waste, fecal matter, and potsherds etc. (Kelly 1973). In Athens in 500 BC legislation was made that required wastes to be discarded at least 2 km outside of town limits (Bilitewski et al. 1997).

Between 27 BC and 410 BC human and animal carcasses from gladiatorial combats were disposed at the city's outskirts in open pits and the law about disposal of fecal matter was adopted by Romans (John 2005).

Since it was not safe to burn wastes in the city limits due to presence of wooden structures (Wilson 1977) wastes remained in place in London and in 1297, and an order was made requiring all tenants to keep a clear pavement in front of their houses, but the order was largely ignored and waste was burnt in household open fires (John 2005). During the mid-1300s kites as well as ravens were protected by law as they fed upon the waste heaps. During this period the pigs roamed on the streets and dogs were innumerable (Rawlinson 1958)

Paper (Fig. 1.9) which constitutes more than 15 % of today's MSW in many parts of the world was invented in China during 2nd century BC. Further, China invented composting and recycling bronze. Also, during this period (Around 500 BC) Athens in Greece made a law to enforce disposal of garbage.

The period saw increase in population, settlement and urbanisation leading to epidemics in many parts of the world, the major one being plague of Justinian which began in 540 AD (Alice 2008). The population of the world touched 500 million in 1300 AD and the first major epidemic swept across Europe in 1348 (Alice 2008) with Florence making law for official inspections of streets as well as removal of solid waste (St-Andrews 2011). Plague was endemic between 1348 and 1665 (Alice 2008).

During the 1350s, "The Black Plague" killed nearly 25 million people in 5 years. Around 1350 Britain made a law mandating clean front yards, but the law was not taken too seriously. Britain introduced the first garbage men for collection of solid waste in the history. These waste collectors identified themselves as "rakers" and their job was to rake up solid waste into a cart every week. In 1388 the English Parliament banned dumping of waste in ditches and public waterways. Around 1407 Britain passed the law declaring waste should be stored inside till rakers to remove it. The city authorities of London announced forbidding throwing rubbish, earth, gravel or dung into the Thames in 1357.

Butcher waste from London was discarded at the centre of Thames River from 1392 onwards to avoid pollution of the river bank. City authorities of London ordained in 1405 that the carts used to transport wastes from the city should be provided with backboards of two and a half feet high in order to avoid rubbish falling on streets. In the early 15th century, informers with respect to throwing of rubbish in the streets of London or into the Thames were rewarded. The first recorded use of packaging began in 1551 in Germany.

The use and manufacturing of paper spread from China to medieval Europe in the 13th century. Progress in the working and dyeing of wool occurred in the 13th century. In Prescott (northern English town), the authorities announced an order in 1580 allowing public to stack solid waste in the street near their doors up to a week prior to removal (St-Andrews 2011).

Paper making technique was introduced in England in 1310 and the first paper bag was made in 1844 in Bristol. Low density polyethylene was invented in 1942 and the first garbage bag was made in 1950 (Jacqueline 2009).

Waste heaps outside of Paris gates interfered with the city's defence in 1,400 and city employed 800 carts to remove filth in 1554. Latrines in London over waterways were legalised with annual fee in 1,383 and the city prohibited latrines over the Walbrook in 1462 followed by other urban ditches and moats in 1477 (Alice 2008). Orders issued in the year 1578 in response to plague outbreaks to keep streets clean and dung heaps were prohibited both in streets and other open spaces. While the waste management in Europe took utmost importance, Asia and Africa stood where they were in spite of colonisation of the Europeans in these continents.

Rittenhouse Mill, Philadelphia started manufacturing paper from waste paper and rags in 1690 (Wikipedia 2011; Matthew 2009) perhaps the first effort towards major recycling.

Benjamin Franklin started the municipal street-cleaning service for the first time in Philadelphia of the USA in 1757 and during the same time period American homes began digging solid waste pits instead of throwing it out of doors and windows (Matthew 2009). This was followed by the first metal recycling in 1776 in the USA (Matthew 2009).

1.5 Waste Management in Post-Industrialization Era

After humans settled in different regions of the world, they started experimenting to evolve new things and ended up in industrial revolution between 18th and 19th centuries. During industrial revolution, new products were evolved and speed of

Fig. 1.10 The first human-made plastic was invented in 1855 which now makes more than 10 % of solid waste in most of the urban area throughout the world

manufacturing increased. Innovation and evolution of fuel driven transport resulted in transportation of goods into new market. As the market for new product increased the waste quantity was also increased. Waste management in post industrialization era could be discussed as below:

Early 1800s many people in England lived by selling material recovered from trash. 'Toshers' worked in the sewers 'Mud-larks' scavenged river banks, 'Dust-men' collected the ash to be used as soil conditioner and brick making (Wasteonline 2011).

During the period many new products and activity contributed to enhancement in waste quantity as well as change in waste quality. Waste management made its entry in many 'municipal acts' throughout the world. But implementation remains still poor as municipalities were not monitored by other agency and officers were not punishable under any law for poor implementation of 'municipal acts'. Industries outside the municipalities were not governed by any law. Industrial manufacture greatly lowered manufacturing cost in the 19th century. Sewing machines used extensively in the 19th century increasing production of cloths. The first human-made plastic was invented in mid 19th century which now makes more than 10 % of solid waste in most of the urban area throughout the world (Fig. 1.10).

A proper waste collection service was first instigated in the Cape Colony in 1786, and by the 1820s a regular waste collection, using animal-drawn carts, was established (CSIR 2000).

Population in 1810 touched 1,000 million, during which there were seven cities in England with population more than 50,000. By 1811 England had eight cities with population of more than 50,000, and by 1821, there were twelve. At the conclusion of the 19th century one-third of the population in England lived in a town (Andrew 1993). London which had a population of 840,000 in 1801 grew to more than a million people by 1811.

During this period waste was collected by "dust-men" in London was recovered/recycled/reused by manual segregation in "dust-yards"(Velis et al. 2009).

Edwin Chadwick's *Report of an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain* in 1874 linked disease to filthy environmental conditions (Wikipedia 2011) and in the same year in Nottingham, England, municipal solid waste was systematically incinerated for the first time (Matthew 2009).

The industrial revolution was the beginning of more materials, trade, and machinery with coal as the largest contributors to the revolution. Over 3.5 million tons was burnt in London in one year. These people started selling waste from dog feces (used to purifying leather) to ash (for adding to mortar). The Public Health Act of 1875 was enacted in Britain to give authority for waste collection. The bins were used to store waste and emptied weekly.

About 250 giant burn plant called destructors were built all over Britain which led to floating of ash and burnt paper all over the country. Around 1757 the first street cleaning service was introduced and public were encouraged to dig pits to dispose their solid waste. America built its first incinerator in 1885 on Governors Island, New York.

The first *waste incinerator* was built in Governor's Island, New York 1885 (Matthew 2009). Waste reduction set up in US in the year 1896 (Wikipedia 2011; Matthew 2009) and New York opened the first waste recycling plant in the USA in 1899 (Matthew 2009). The early use of incinerators in the USA was failure due to faulty design and construction and hence 102 of the 180 incinerators installed in the USA between 1885 and 1908 were deserted by 1904 (Wilson 1986; Blumberg and Gottlieb 1989, John 2005).

The population became 1608 million in 1900 AD. The USA's first major aluminium-recycling plants were opened in Cleveland and Chicago in the year 1904(Matthew 2009).

More than 100 incinerators were closed in the USA in 1909 due to noxious smoke but by 1914 more than 300 incinerators were functioning in 1914 in the USA and Canada for combustion of waste (Matthew 2009). Sanitary landfill was introduced in England for disposal of solid waste in 1912. The city of Olympia in the USA started paying for aluminium cans in 1954. Quantity of municipal solid waste increased from 88 million 1,960 tons to over 208 million tons in 1995 (Keep America Beautiful Inc 1996). US enacted the first solid waste management law in 1965. Spread of AIDS causes flourishing of disposable needles.

Dumping waste in ocean, wetlands, waste land was common practice in Europe during 1908. While the USA collected 71 % of solid waste in 161 large cities, small towns and cities continued feeding waste to pigs. The first aluminium recycling plant commissioned in Cleveland and Chicago.

Cities of the USA began switching from horse-drawn to motorized waste collection equipment during 1916 and using wetlands for disposal of waste became popular during 1920s followed by banning of municipal waste dumping into oceans by the supreme court of the USA in 1934 (Matthew 2009).

In the 1920s of mechanical transport in solid waste management in South Africa was introduced (CSIR 2000). The palace, forts and religious place like temples in India were swept and kept clean but waste is not hauled to great extent.

Fig. 1.11 *White* goods have increased many folds in the present century

As the waste was degradable it was composted or thrown away without much impact on environment. While the dead animals and placenta (during birth of people and animals) are usually buried, the discarded butcher wastes were usually picked by birds or street dogs. The urbanization took a new dimension in British rules and cities grew. Institutional arrangement for solid waste management by municipal authorities in India came into being in the 18th century British regime (Da et al. 2008). The king of Patiala in India converted cars into garbage vehicles in 1930.

100 cities in the US were using sanitary landfills around 1945 (Matthew 2009). After the World War II, open burning dumps and backyard waste burning was prohibited in most areas. Consumerism becomes high and America was named as "throwaway society". Disposal of packaging material increased by 67 % after World War II with consumerism and obsolescence becoming entrenched in now developed countries.

Clean Air Act is passed in Britain in 1956 replacing solid fuel used for heating house by with gas and electricity.

The period saw dramatic increase in disposable paper cups and plates followed by plastic cups, and plates as well as cutleries. During this period, corrugated cardboard became popular as packaging and the first beer can were introduced.

With Solid Waste Disposal Act in the USA, the government placed emphasis on inventory, recovery, and research and solid waste grants. Concept of the "Transfer station" was introduced during this period. UN's first major conference on international environmental issues was attended by the representatives of 113 countries. 'The United Nations Conference on the Human Environment held in Stockholm, Sweden between June 5 and 16, 1972 marked a turning point in waste management. White goods increased many fold during the period (Fig. 1.11). Affluence also contributed to new wastes which were not produced earlier (Fig. 1.12).

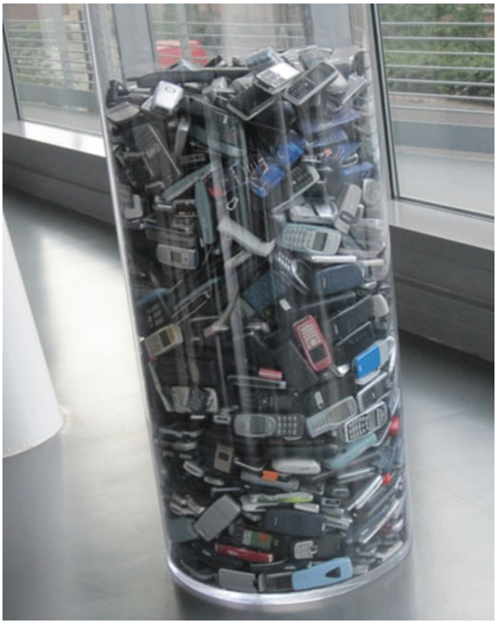


Fig. 1.12 Affluence has resulted in 'use and through' culture

Plague causes widespread havoc in India and Vietnam in 20th century with confirmed and suspected human cases touching 28,530 with 2015 deaths during the year 1994–2003 (Thomas 2009). Plague hits Surath in India in 1994 due to which the city authorities took extensive measures to manage solid waste. Asia witnessed the Severe Acute Respiratory Syndrome (SARS) outbreak and avian flu from birds to humans. Millions of fouls were killed and biomedical waste attracts special attention.

The world's population touched 6080 million in 2000 AD and 6450 million in 2005. Global MSW touched around 1.3 billion metric tons in 1990 (Beede and Bloom 1995) whereas as per (Suocheng et al. 2001) the global MSW was around 0.49 billion tonnes for the year in 1997. Total global solid waste touched nearly 12 billion tons in the year 2002 (Pappu et al. 2007) out of which 11 billion tons were from industrial wastes and 1.6 billion tons were municipal solid wastes (Safiuddin et al. 2010).

During this period USEPA made standards for landfill groundwater protection in 1991 along with post closure care in the USA.

In this period, societies started wasting food more than ever in developed world. Societies wasted food from 5 to 30 % in the past and current century. The yearly generation of food waste in Singapore alone was 542,700 tons during 2006 and 570,000 tons during the year 2008 (NEA 2009).

China made progressive and dramatic economic growth during the verge of last century. Amount of solid waste has increased from 220.0 thousand tonnes in 1990 to 3,613.6 thousand tons in Beijng during 2003 due to rapid economic and population growth (Xiao et al. 2007). Studies conducted by Xiao et al. (2007) revealed food waste, paper and plastic showed increasing trend since 1990 in MSW in Beijing whereas ash and woodchips content started declining.

During this period, scientific progresses lead to invention of numerous chemicals and merchandise. Innovation in electronics and computer science lead to generation of WEEE. The rich countries start smuggling out the waste to poor which ultimately ended in formation of international laws to combat trans-boundary movement of waste.

Future

Since 1987 the population of world has increased by about 34 percent and at the same time world trade has increased by 2.6 times (UNEP 2007) resulting in more consumption of resources and generation of waste. There is also shift in urbanisation pattern and consumption pattern with developing countries spending more money on things they never consumed. Due to cheap labour the developed countries are shifting the industrial activates to developing countries.

As per Yoshizawa et al. (2004) global annual solid waste generation is likely to touch 19 billion tons/year by the year 2025. It is estimated that urban areas in Asia are producing nearly 760,000 tonnes of MSW every day (about 2.7 million m^3/day) and in 2025, this figure would increase to 1.8 million tonnes of MSW per day, (about 5.2 million m^3/day) (World Bank 1999). Densely populated cities in Japan, Singapore, Malaysia, Thailand, South Korea, China, Indonesia and the Philippines are thus under pressure to modify their solid waste systems and shift from only disposal to recovery of energy and materials (UN-Habitat 2010a). Availability of freshwater is diminishing globally with 1.8 billion people living in regions with water scarcity (UNEP 2007) implying there will be more turnover in packaged water industry and hence more disposable plastic bottles.

Change in climate and subsequent disaster would add to the waste burden as there would be more debris to dispose off. The drop in oil and mineral reserves will force people to find alternative to cement, metal and petroleum products thereby changing waste characteristics and possibility of mining landfill sites for resources cannot be ruled out in future.

1.6 Integrated Solid-Waste Management

Integrated solid waste management (ISWM) is comprehensive waste management which includes prevention, recycling, treatment, and disposal program. It considers how to manage solid waste most effectively to the environment and human health. Waste management planning should consider institutional, financial, economic, social, legal, technical, and environmental factors. Figure 1.13 shows schematic diagram of components of ISWM and Fig. 1.14 shows ISWM planning process.

The sustainable management of solid waste is necessary from planning to design, to commission, to operation, to shut down, and to decommissioning. Hence

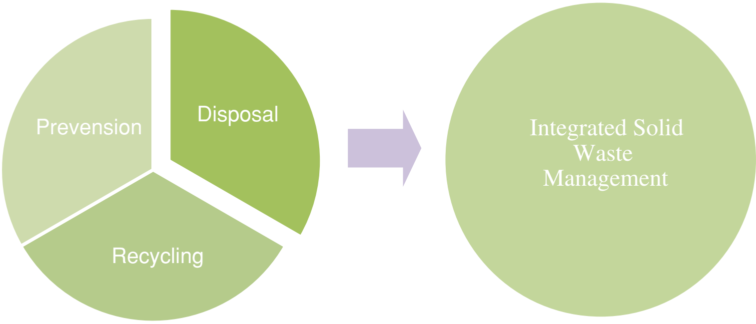


Fig. 1.13 Components of integrated solid waste management

the range of new and existing waste management technologies and strategies has also spanned from preserving environmental quality as on date to meet goals of sustainability in the future (Ana et al. 2010). Such an orderly evolution permits both waste management industries and government to meet needs of waste management with green potential, to recycle materials, to expand the renewable energy supply, to search for socially acceptable options, and to conserve biodiversity simultaneously.

Integrated solid waste manage should integrate: (1) Cost Benefit Analysis (CBA), (2) forecasting waste generation trends, (3) Material Flow Analysis (MFA), (4) Life Cycle Assessment, (5) Risk Assessment (RA), (6) Environmental Impact Assessment (EIA), (7) Strategic Environmental Assessment (SEA), (8) Socioeconomic Assessment (SoEA), and (10) Sustainable Assessment (SA).

1.7 Waste Prevention and Life Cycle Assessment

Life cycle assessment (LCA) informs the fate of waste within the system. *LCA* is a holistic approach to waste prevention by analyzing the life of a product/process/activity which includes procuring raw materials, storage of raw material, manufacturing, storage of products, packing of products, transportation, distribution, use, reuse, maintenance, recycling, waste storage, waste transportation, waste management and disposal.

Syringe and needle are important in control of diseases by immunisation, diagnosis and treatment. Figure 1.15 shows the life cycle assessment of syringe and needle. It is very much important to note that the society is safe as long as the plastic and metal comes from virgin source or after proper infection. If the syringe and needle takes a short cut then obviously society has to worry about impact on human health.

One problem with LCA is reports prepared by consultants will be usually in the favour of the industry. Life cycle analyses suffer from a lack of data. Most of the

Fig. 1.14 Integrated solid waste management planning process

important information for LCA is not possible to obtain. In the above example if million infected syringes and needles are coming back to society, government authorities will face embarrassment for not taking action against culprits.

Once the life cycle has been analyzed, the next step is to manage it. Even though it looks simpler in terms of theory, practically it may not be unachievable. The cracker manufacturing involves child labor in many countries, avoids huge tax, produces large waste, damages environment and lives hundreds of children permanently disabled. But still governments are unable put total ban on the product. The examples can also be drawn from cigarette and alcohol manufacturing as they are dangerous to health, source of large quantity of carbon, degrades

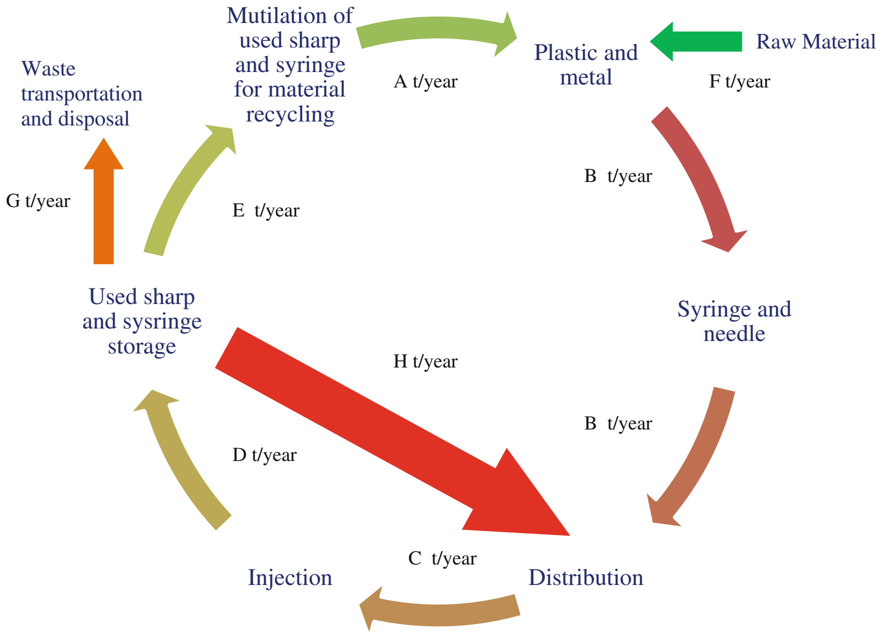


Fig. 1.15 Life cycle of syringe and needle

environment and generates huge waste. Avoiding these products does help the society but countries often retain these industries and products.

There are many examples of reducing waste by encouraging reuse of printer cartridge, container, packaging material, recycling scrap etc. Such decisions have helped the industry to cut costs and increase margins.

1.8 Producers Responsibility

The important characteristic of Extended Producer Responsibility (EPR) policies is that responsibility for a product's environmental impacts at the end of life is placed on the original producer/seller. EPR is an extension of the "polluter pays" principle and aims to ensure producer take responsibility for those products which have reached the end of life.

The intention of placing such responsibility is to make producers necessary arrangements to reduce waste by improving product recyclability/reusability. The term *extended producer responsibility* was first used in Sweden and concept has adopted in many countries. The German packaging "take-back" law was based on the EPR principle. Measures to be taken for EPR include: (1) improving product recyclability/reusability, (2) downsizing products, (2) reducing material usage, and (2) engaging "design for environment" (DfE) activities.

The common instruments for achieving EPR are: (1) *product take-back mandate*, (2) *recycling rate targets* (*RRT*), (3) *RRT*, *with tradable recycling credit scheme*, (4) *voluntary product take-back with RRT*, (5) *advance recycling fees*, (6) *ARF combined with a recycling subsidy*, (7) *landfill bans*, (8) *pricing of waste collection/disposal*, (9) *recycling subsidies*, (10) *recycling investment tax credits* (Margaret Walls 2006)

The producer responsibility was introduced in Sweden by law in 1994. The legislations enacted by Sweden with respect to EPR are (1) Ordinance (1994:1205) on producer responsibility for news prints, (2) Ordinance (1994:1236) on producer responsibility for tyres, (3) Ordinance (1997:185) on producer responsibility for packaging, (4) Ordinance (1997:788) on producer responsibility for vehicles, (5) Ordinance (2000:208) on producer responsibility for electric and electronic products.

The Producer Responsibility Obligations in the UK are intended to achieve the minimize/recover/recycle packaging waste. Under these regulations the quantity of waste to be revered by each business is determined by: (1) the quantity of packaging the business handles, (2) the business recovery/recycling targets for the year, (3) the packaging activity carried out by business.

1.9 Solid Waste Management and Regulation

Since the second half of the last century, the environment became an important issue at the global level. Law with respect to nuisance were considered as a local or regional phenomenon until the world conference organized by the UN in Stockholm during, 1972 gave it a global dimension. The international society showed its attention in the environment through a range of international conventions and treaties covering major environment issues with a view to protecting environment. As on date these soft laws exceeded a number of 150 globally.

One of the widely used methods to prevent environmental damage at national/regional level is through permits.

After 1972 Stockholm conference, governments all over the world have supplied the laws to their citizens even though implementation of them to the trueness of objective is still questionable. Many of these legislations have been formulated to satisfy judiciary system of the country or international community. In many cases courts have directed their respective government to bring out new legislation and in other cases international community have influenced the government to adopt sophisticated legislation. But mere passing notification or enacting environmental legislation cannot guarantee it implementation. Most of the developing nations have failed to address corruption, shortage of manpower in agencies responsible for implementation of environment legislation, political interruption in day to activity of agencies responsible for implementation of environment

Fig. 1.16 Driving wheels of pollution control legislation

legislation, absence of monitoring during holidays and nights, upgrading technical capability, and any other administrative issues.

As shown in Fig. 1.16 awareness, incentives, warning and punitive action are the main components in implementation of pollution control legislation. Environmental legislation which includes environment conservation and pollution control is usually criminal legislation. Thus as soon as an environmental legislation is passed most of the stakeholder responsible for compliance to legislation will turn out to be environmental criminal. Hence regulatory authority would usually create awareness which is sometime supported with incentives like subsidies tax benefits. Ultimately non-compliers will be warned sufficiently and given opportunities under principle of natural justice before initiation of punitive action. The component of opportunities under principle of natural justice is intentionally made part of environmental legislation as most of the violation could happen by elite citizens like entrepreneurs and civic authorities. Hence the violators would be issued with notices and personally herd by enforcing authorities prior to initiating punitive action.

Although there are abundant laws for the developed countries since more than a century, there is no uniform enforcement (Garbutt 1995; Lieberman 1994). Enforcement of legislation about waste in the developing world is the major problem (Ajomo 1992; Adewale 1996; Onibokun et al. 1999).

A range of stakeholders and actors need to be involved in designing regulations as participation ensures understanding and acceptance of law. But practically it is difficult to bring together all the concerned stakeholders. More support at the national and the international levels is also sought-after to ensure that international agreements are implemented.

As shown in Fig. 1.17 regulatory issues in solid waste management does not deal only with waste management but also with other social issues like child

Fig. 1.17 Regulatory issues in solid waste management not only deal with waste management but also with other social issues like child labour

labour as well. Developing world employs substantial number of youngsters in waste management due to cheap labour.

1.9.1 Need for Regulation

Unlike the historic days many countries have separate legislative, executive and judiciary systems. Even though loopholes within this system exist, a country may make a law to impress international community.

Keeping all the negative aspects of system aside, a country needs regulation of solid waste for following reasons

- To guide the stakeholder about their responsibility;
- To monitor the waste regulating activity;
- To maintain records about past waste regulation and improvements thereupon;
- To bring in an amendments to existing legislation;
- To form basis for citizens and NGOs to approach judiciary system; and
- To have a permitting system in place.

But enacting acts and passing rules would not make things better. There need to be substantial and clear communication to all stake holders. As shown in Fig. 1.18 a large banner not to put garbage and applicable fine has resulted in the desired result.

Fig. 1.18 Example of effective communication through better communication

1.9.2 International Regulation

Nearly 98 % of the world's hazardous waste is generated in the developed countries. International waste traders have passed on large quantities of wastes to developing countries. The main reason could be attributed to economic imbalance, weak enforcement of environmental laws, absence of ethics among traders, absence of environmental concern, easy and cheap recycling. Scrap metal from developed countries have great demand in developed countries where there is huge number of foundries operated at lower cost due to availability of cheap labour and energy. The Basel Convention, which was adopted on 22 March 1989 to stop movement of hazardous waste from one country to other country. The Final Act of the Basel Convention was signed by 105 States, and European Community (EC). The Convention entered into force on 5 May 1992. Many countries have now passed legislation enlisting waste that cannot be imported into their territory.

Many international laws require states to license potentially harmful activities:

- Oslo Convention for the Prevention of Marine Pollution by dumping waste from Aircraft and Ships;
- Bonn Convention on Protection of the Rhine against Chemical Pollution;
- Paris Convention for the Prevention of Marine Pollution from Land-Based Sources;
- London Dumping Convention;
- Basel Convention on Hazardous Waste;
- Bamako Convention on Hazardous Waste in Africa;
- Antarctic Treaties;
- Regional Seas Agreements;
- ASEAN Agreement on the Conservation of Nature and Natural Resources; and
- African Convention on the Conservation of Nature and Natural Resources.

The Convention on the control of trans-boundary movements of hazardous waste and their disposal (22 March 1989), or the Basel Convention, was initiated in response to several international scandals regarding hazardous waste trafficking in the late 1980s (BAN 2010). The Convention entered into force in 1992 and amended on 22 September 1995 and re-amended in on 10 December 1999. The

Convention on the ban of import into Africa and the control of trans-boundary movement and management of hazardous waste within Africa (29 January 1991) also known as Bamako Convention, places a total ban on the import of hazardous waste to signatory countries.

In an attempt to ban importation and to control hazardous wastes in the region, Waigani Convention was adopted in 1995 to Ban the Importation into Forum Island Countries of Hazardous and Radioactive Wastes and to Control the Transboundary Movement and Management of Hazardous Wastes within the South Pacific Region.

Dumping of MSW in ocean is banned/restricted by legislation in most of Africa due to the London Dumping Convention of 1972 as well as Lom and Bamako conventions. In spite of such legislation dumping still occurs in larger coastal cities of Africa (African Development Bank 2002).

1.9.3 Regulation in Different Countries

National regulations are formed through Acts and Rules. Acts at national level are offspring of national constitution and anything said in act should not be against constitution. Where ever written constitution is not available, the acts are formulated considering national policy, international laws and other procedures specific to the country. The acts are formally enacted in parliament or assembly by legislative wing of government. Rules are framed afterwards considering the provisions within the parent act. Rules cannot have provisions which are not there in its parent act (act under which rules are framed). National environmental legislation in their preambles lay out definitions of important words, terminologies and concepts. Later the purpose of legislation is explained followed by elaboration of law. The laws will fix responsibility to concerned authorities and stakeholders. The penal action for violation of responsibility will be made part of environmental legislation for enforcement. If penal provisions are not present in the rules then reference is made to its parent act.

Governments are monopoly suppliers of laws and there are various reasons for formulation and enforcing national regulation. The Philippines enacted the Ecological Solid Waste Management Act during the year 2001 after collapse of dumpsite which resulted in more than 200 death in the Payatas in 2000 (UN-Habitat 2010a). Malaysia enacted 2007 Solid Waste Management (SWM) and Public Cleansing Act in 2007 in order to federalize SWM and progress the nation to status of a developed country by 2020.

When dealing with pollution and solid wastes, one should have knowledge of applicable multiple laws and all applicable legal instruments (Fig. 1.19). Constitution in a country is the apex instrument and all acts shall be in accordance with constitution. All provision within any instruments subsequent to an act should be in accordance with the act. Environmental compliance demands a keen knowledge of all the environmental laws in the nation.

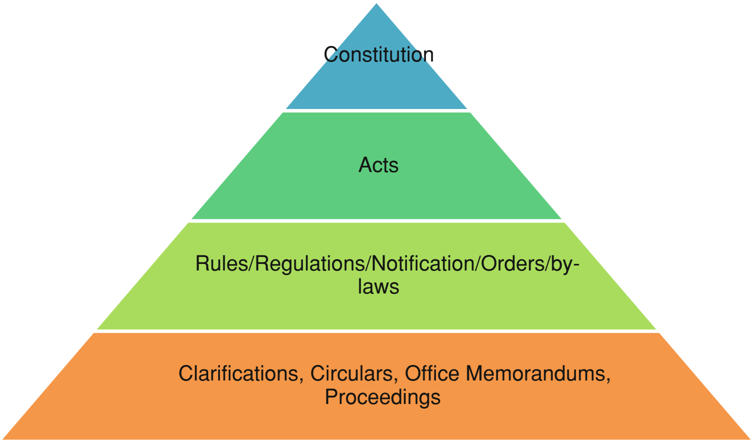


Fig. 1.19 Hierarchy of legal instruments

Over the years the governments have learnt that they cannot take all the responsibility and hence has constantly placed responsibilities on different stake holders. After passing array of legislations the governments have gained knowledge of shortfalls within the existing legislation and passed fresh legislations. Advanced legislations like *Comprehensive environmental response*, *compensation*, *and liability act* in the US binds legal responsibility on industries to share the costs of remediation due to damages caused after disposal of waste. When wastes as well as pollution are created by industry, it maintains liability forever (that is ownership of waste cannot be passed on). When an operator of landfill accepts waste for final disposal there is the risk that wastes can contaminate the groundwater due to breach of the landfill liner. While the operator of the landfill is responsible for remediation, the generator of the waste also has legal responsibility to share the costs of remediation by *joint and several liabilities* (Nicholas 2003). But such sophistication has not reached all parts of the world especially developing world which is still struggling to enforce the existing environmental legislation efficiently.

Regional and local regulation comes into picture where country has been divided into different regions or states for administrative purpose. The administration in regional levels will function based on the responsibility of regional governments fixed in constitution/act. Hence states or regional province will have list of subjects over which it has exclusive authority. Some time some subject will be handled both state and federal government. In some other issues states does not have any authority at all. The federal government authorities usually have complete authority with respect issues like defence, external affairs, aviation, etc. The regional government will regulate police, regional environment, local resources etc.

As discussed earlier each law will have regulatory bodies which are responsible for implementation of legislation. These bodies register or issue permits/licence to carry out certain activities with certain conditions. The recipients of permit/licence will carry out business as per the conditions stipulated in permit/licence. The failure to comply with the provisions of legislation of conditions of permit will draw attention of regulatory bodies.

Duties of regulatory bodies include formulation of policies, dissipation of provisions of regulation and enforcing the laws. It often argued that ‘innocence of law is not an excuse’. But without proper interpretation and awareness among the people it will not be possible to achieve objectives of the legislation.

Legislations adopted by some of the countries are given in Table 1.1. Apart from these legislations many countries have legislation in place, Japan has passed the home appliance recycling law (Zhang and Kimura 2006). In Vietnam, the importing second-hand EEE was banned in 2001 and in May 2006, the enforcement was tightened (Shinkuma and Huong 2009). In South Korea, WEEE is regulated by the waste management act (Hyunmyung and Yong-Chul 2006). *Environmental protection administration recycling management fund* was introduced by Taiwanese Government in 1998 to support the collection, transportation and disposal of WEEE (NEP 2006). Kenya is a party to both the Basel and Bamako Conventions, but there is no structured system of WEEE collection in the country (Mureithi and Waema 2008). South Africa has ratified the Basel Convention, but not ratified the Bamako Convention (Liechti and Finlay 2008). Any waste legislation will define two set of people: (1) Regulators, and (2) Waste managers. Waste have two legislations invariably fix the responsibility on enforcing agencies which shall act on defaulting waste managers and waste generators. The legislation also elaborates responsibility on implementing agency like ULBs, industries, commercial establishments, etc. The reasons could be one or many of the following

- Waste management may not be priority;
- Loop holes within the legislation;
- Corruption;
- No respect or less respect to the law of land;
- Legislations are made to impress international community instead of for enforcing for the benefit of country;
- Law implementing/enforcing officer will be political nominee who yields and accepts political intervention;
- Politics among the employees within the enforcing agencies;
- Enforcing agency itself is controlled by numerous other legislations (for recruitment, financial auditing, labor related legislation) and hence much of the resource is spent on other legal issues rather than concentrated efforts on waste management;
- Poor infrastructure and absence of funds for waste management;
- Misuse of office vehicle, equipment and other resources by higher officials and peoples representatives;
- Pressure on officials to provide business to relatives and friends of people in higher position;
- Officers of enforcing and waste managing agencies are often deputed for election duty; cultural/sports events; and to attend personal and family needs of people in power;

Table 1.1 Legislations in various countries

Sl. No	Country	Legislations
1.	Australia	Hazardous waste (Regulation of Exports and Imports) act, waste avoidance and resource recovery act, the waste avoidance and resource recovery levy act, the waste avoidance and resource recovery regulations, the waste avoidance and resource recovery levy regulations
2.	Austria	Waste management act
3.	Azerbaijan	The law of Azerbaijan republic on industrial and domestic waste
4.	Bangladesh	Bangladesh environmental conservation act
5.	Cambodia	Sub-decree on solid waste management No. 36 ANRK.BK
6.	China	Solid waste disposal act, toxic substance management act
7.	China	Law on prevention of environmental pollution
8.	India	Hazardous waste (Management and Handling) rules, biomedical waste (Management and Handling) rules, municipal solid waste (Management and Handling) rules, e-waste (Management and Handling) rules
9.	Iran	The law of protection and improvement of the environment
10.	Kiribati	Special fund (Waste Material Recovery) act 2004
11.	Malaysia	Environmental quality (Prescribed Activities/Environmental Impact Assessment) order
12.	Mongolia	Law on household and industrial waste, law on the import, export and cross-border transport of hazardous waste
13.	Marshall Islands	Solid waste regulations
14.	Nepal	The environmental protection act
15.	Palau	Solid waste management regulations
16.	Papua New Guinea	Dumping of wastes at sea act
17.	Philippines	Ecological solid waste management act, republic act No. 9003, Toxic substances and hazardous and nuclear wastes control act, republic act No. 6969, Penalty for improper garbage disposal presidential decree No. 825, Anti-dumping act
18.	Scotland	The waste (Scotland) regulations
19.	South Africa	The national environmental management act
20.	Tonga	Waste management act 2005
21.	Uzbekistan	Joint regulation of the committee of environment

- Inability to hire services of competent knowledgeable advocates/experts;
- Inability to train personnel;
- Loss of man power due to leave availed by waste managing and enforcing personnel;
- Unethical accounting like reporting more vehicles and expenditure than actually been used/hired;
- Threat to waste managing and enforcing officers from rich contractors;
- Shyness to acquire and adopt technology;
- Transfer of officials from enforcing agency to waste management agency and vice versa resulting in poor enforcement;

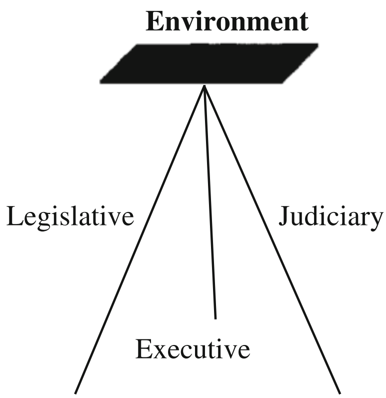


Fig. 1.20 Tripod model of interdependency of Legislative, Executive and Judiciary wings of government in supporting environment

- Position of a waste managing officials being more than that of enforcing officials;
- Fear within the officials of enforcing agency to take action on business belonging to ministers and other people in power;
- Delay in hearing and disposal of cases in court of law with respect to waste;
- Defaulter will not be punished due to lack of evidence;
- Recruitment of incapable persons;
- Poor administration;
- Promotion of corrupt and incapable persons within the enforcing agencies and denying growth opportunities to honest and knowledgeable persons;
- Frequent transfers of officials in enforcing agencies;
- Man power on records being different from that in reality due to leaves availed by staff; and
- Inability of press and other media to report improper waste disposal.

Apart from above there could be other reasons which is beyond understanding of experts and not reported, published. As a result international community is still unable to find a full proof solution.

Gaoussou and Sebastien (2011) suggested effectiveness of regulatory institutions depends on: (1) firm's environmental non compliance as well as petty corruption (firm-inspector relation), and (2) judicial efficiency.

There is rise in waste/pollution in developing countries due to relocation of industries from developed countries due to lower environmental standards, and cheap labour. As a result there is rise in waste in last decade in these 'pollution heavens'. Corruption and rent-seeking actions in many countries has paralyzed the environmental legislation copied from else ware. Pollution levels consequent to corrupt behaviour are above the socially optimal level (Ram′on and Siddhartha 2000).

Figure 1.20 shows support required by legislative, executive and judiciary wings of government to protect environment. Mere passing a legislation to convince international community does not protect environment. Similarly if judiciary drags the case dozens of years instead of interpreting and passing verdict at right time, environment will be affected. On the other hand executive wing should act upon the culprits to safe guard environment instead of just collecting 'rent for not acting'.

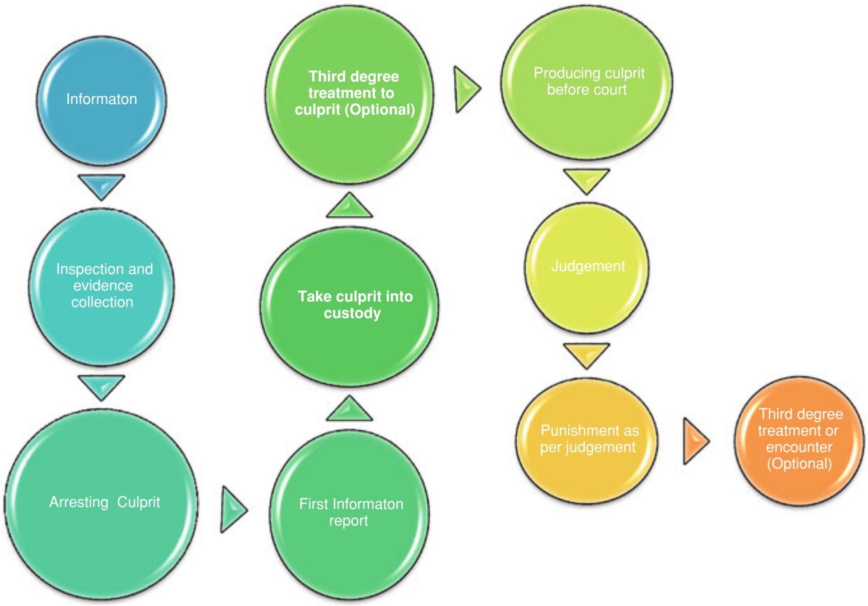


Fig. 1.21 Punitive procedure in case of conventional crime

Environmental legislations are typically classified as criminal laws. Environmental legislation is of two types namely (1) resource/wild life conservation, and (2) pollution/waste control laws. But procedure followed in punitive procedure for proving the crime and identifying culprit before taking punitive action is quite different than that of the procedure followed in conventional crime. Figure 1.21 shows punitive procedure in case of conventional crime. Figure 1.22 depicts punitive procedure in case of pollution/waste related environmental crime.

In case of conventional crime like murder, robbery, violence the police will take evidence and take suspecting people into custody and produce before court. It is quite common all over the world to give third degree punishment like physical assault of suspect while investigating conventional crime compelling the him/her to accept the crime. Suspects are also killed some time in encounter while investigation or afterwards.

In case of pollution/waste related environmental crime suspects are not taken into custody. Suspects will neither be given third degree treatment or killed in encounters. The cuprites will be given ample opportunity under principle of natural justice. The culprits will be issued notice seeking reasons why action should not be taken against them. Such notices which are called ‘Show Cause Notice’ will provide time to criminal to rectify fault or time to think to about reason. Apart from notice the pollution/waste related environmental criminals are also personally heard by enforcing authority prior to initiating action except in highly exceptional cases (like pollution which might have affected people/environment significantly).

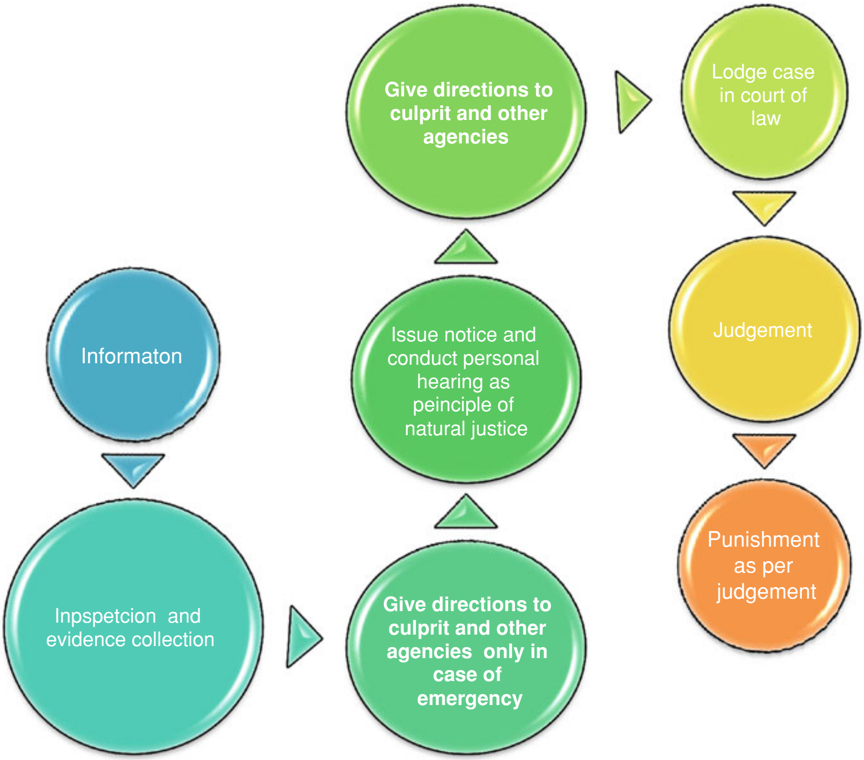


Fig. 1.22 Punitive procedure in case of pollution/waste related environmental crime

1.10 Framework for Solid Waste Management

In the tremendously competitive world of business frame work for solid waste management depends on the development of a nation, type of solid waste and quantity of solid waste generation.

Frame work used in urban waste management depends on the population of the urban area. The collection and transportation of waste will become more complicated with increase in size of urban area. Industries and major commercial operations often will have private arrangements for the many of the waste generated by him. Local bodies often will not have capability to accept hazardous, radioactive and infectious waste which needs to be disposed within captive facility of common disposal facilities.

The waste management becomes complicated if the cities have grown without proper planning. Many of industrial clusters in developing countries, which were in the outskirts of cities decades ago, have now at the centre of the cities due to growth of urban bodies over the time making it difficult to haul waste in through thickly populated residential or commercial area.

A solid waste management system comprises a few or all of the following actions:

- Formulation of policies;
- Formation and enforcing laws;
- Planning and evaluating activities including formulation of financial plans; involving private sector businesses; identifying environmental damages and formulation of environmental management plan; Assessment of health and safety issues along with remedies; and establishing prices for services.
- Collection, transporting, treatment, disposal of waste and marketing recovered materials;
- Training to solid waste management handlers;
- Creating awareness to all stake holders including generators and public;
- Creating incentives;
- Safeguard livelihood of people who depend on solid waste; and
- Incorporating emergency preparedness.

Material flow in a society will usually follow the illustration in Fig. 1.23. The *Waste Management Hierarchy* is shown in Fig. 1.24. Minimization, recovery and transformation, and disposal on land are implemented by most developed countries for developing solid waste management schemes. But avoiding waste is yet to gain its momentum. The waste avoidance can occur by banning the product which is not environmental friendly or good for society. Examples of such items include intoxicating drugs, cigarettes, alcohol, crackers etc. Many parts of the world have banned many items. Gujarat state in India has put total ban on selling and consumption of alcohol. The degree to which any one alternative is utilised in a nation largely depends on a numerous factors like transportation, population density, topography, socioeconomic and environmental regulations (Sakai et al. 1996).

1.10.1 Elements of a Waste Management System

Sustaining SWM requires interrelated elements to be properly liked. SWM elements can be listed as: (a) policy, law and planning, (b) waste handling, (c) training, (d) awareness, (e) safeguard livelihood incentives, and (f) emergency preparedness

The inter-relationship among the elements is shown in Fig. 1.25. Policy, law and planning are essential part of SWM as without them there would not be any clarity among the stakeholder about their roles and responsibility. As could be seen from the historical development of SWM the people tend to dispose the waste indiscriminately in the absence of law. The laws would not act themselves and needs proper implementation of waste handling for which the training is required for both enforcing as well as managing. Apart from training the waste generators needs wide awareness for changing their behavior which has been done through posters, handouts, publicity in mass media like internet/Radio/Newspaper/Tele Vision etc.,

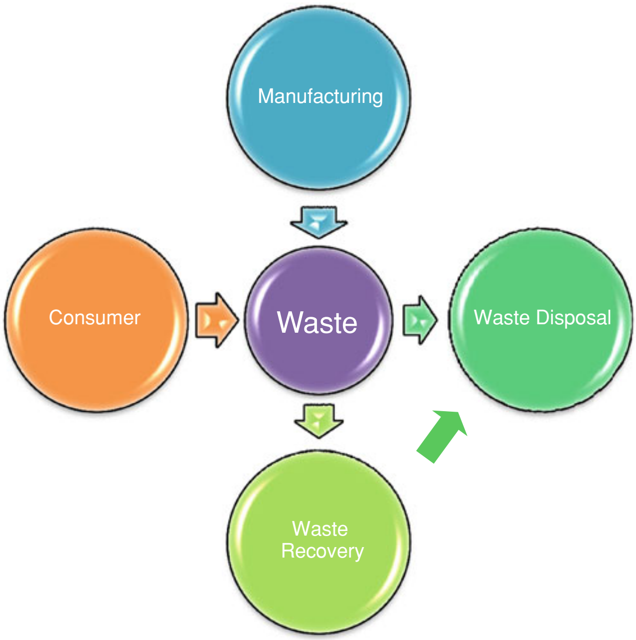
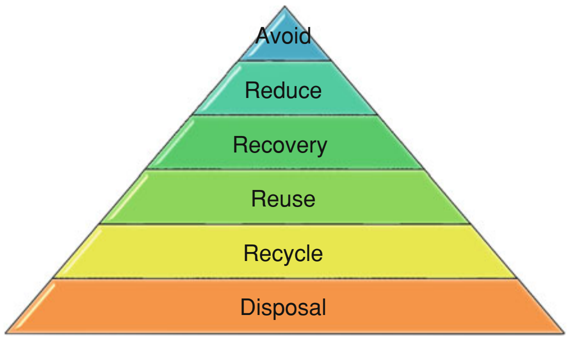


Fig. 1.23 Material flow and generation of waste in society

Fig. 1.24 Waste management hierarchy



It is essential that the waste management should not just take leap by bringing in new set of people for managing. It is observed that many countries about one to two percent of urban population depends on solid waste for livelihood. It is essential that new policies consider the livelihood of people who depend on the waste. Ultimately most of the SWM programmes neglect safety and emergency preparedness leading to injury and death of waste managing staff and general public.

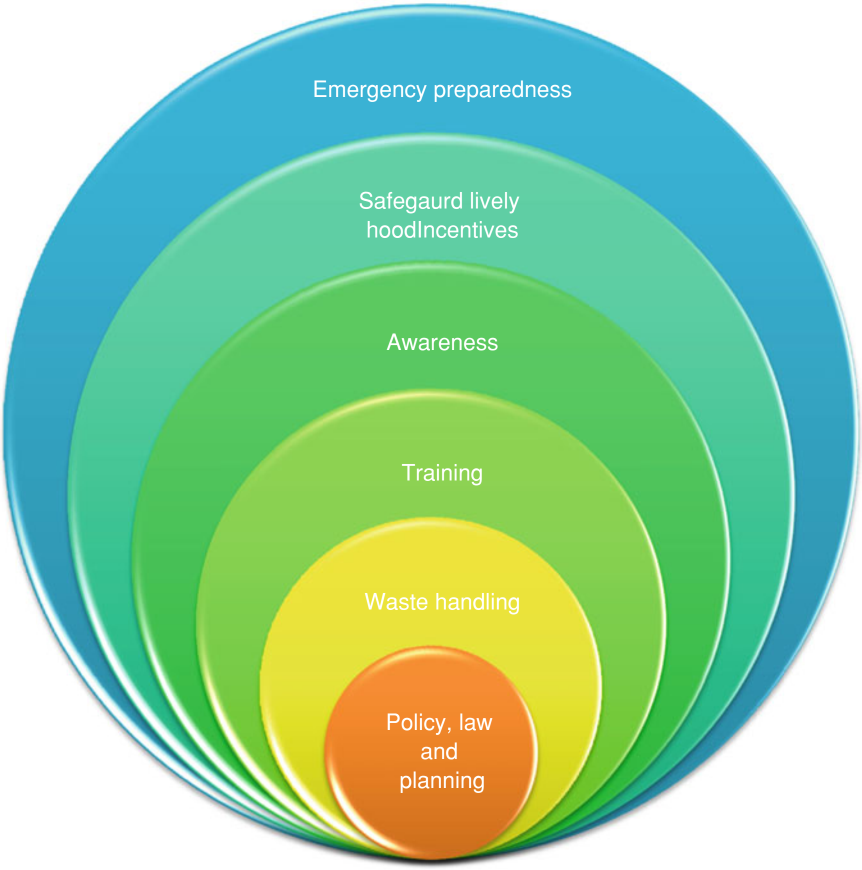


Fig. 1.25 Elements of waste management

1.10.2 Stakeholders

Solid waste management is not a decretory activity with limited stake holders. It involves almost everyone in the world and organizations in almost all sectors. Figure 1.26 shows classification of stake holders in solid waste management.

The stake holders at national level include (1) waste generators; (2) local bodies; (3) private waste handlers; (4) employees of local bodies and private waste handlers; (4) local, regional, national government; (5) Non Government Organisation(NGO)s; (6) community based organisation; (7) industries that generate waste; (8) recycling industries; (9) commercial establishments; (10) waste pickers; (11) scrap dealers; (12) consultants; (13) financial institutions; (14) media; (15) citizens; (16) Self Help Groups (SHG); and (17) waste processing and disposal organisations.

Fig. 1.26 Classification of stake holders in solid waste management

The stake holders at international level include: (1) international organisations, (2) international donor agencies and lending agencies, (3) international waste handling companies, (4) international NGOs, (5) scrap importers and exporter, (6) media,; and (7) international consultants.

1.11 Financial Issues in Solid Waste Management

As per World Bank (1999) local governments of Asia spent approximately US$25 billion/year on urban solid waste management. Such estimation would clearly indicate the inefficiency of the systems adopted by local government in Asia.

Proper management of waste needs proper financial and economic foundation. Waste management services require funding for collection, storage, transport, treatment and disposal. These activities invariably need funds which come mostly from government. Environmental legislations require industries and major commercial establishments to spend money for proper management of waste until final disposal which is monitored by government.

At individual and community level expenditure is recovered by collecting taxes in the form of property tax and cess. In addition to this financial base, local bodies seek assistance from regional and state government which in turn may seek financial assistance from federal government or international donor/lending agencies.

Like any business solid waste management has expenditure and revenue. The expenditure in solid waste includes capital investment and operational investment.

The capital investment includes investment made on (1) waste collection equipment, (2) waste transportation vehicles, (3) land for waste disposal facilities, (4) waste handling equipment, (5) office building and equipment, (6) infrastructure like roads, electric connection, pollution control equipment, water supply to waste handling sites, and (7) investment towards safety, environment monitoring.

Operational costs include expenditure accounted and unaccounted in official records. Major expenditure include: (1) Salary to waste handling staff and office staff, (2) stationary, (3) energy/fuel, (4) office stationary, (5) communication, (6) chemicals/other consumables, (7) training, (8) insurance, (9) statutory fees, (10) consultancy/auditor/advocate/legal fees, (11) training, (12) vehicle maintenance, (13) equipment maintenance, (14) bribe to government agencies, (14) party funds for political parties, (15) payment/expenditure to local community to maintain good will, (16) payment to other organisations which may threaten the operators, (17) safety equipments, (18) environmental monitoring, (19) official travelling/entertaining clients/entertaining government officials, (20) beverages and refreshments for stakeholders, (21) health check up and vaccination of employees, (22) unforeseen expenditure due to accidents, (21) interest towards loans if any.

Revenue generation occurs by (1) collection, transportation and handling fee, (2) analysis fee, (3) subsidy, (4) financial assistance from government or international agency or others, and (5) revenue from selling recyclable/reusable material.

Municipal solid waste management throughout the world is considered as a duty of municipality. But due to lack of funds and resources the local bodies often fail to fulfil their obligation and outsource part of their responsibility. Major action outsourced includes collection, street sweeping and transportation. But such outsourcing operation may lead to inefficiency due to corruption in the system wherein contractors may have to pay the government agency huge bribe and hence avoid service to save cost towards expenditure born towards corruption.

Transportation is important expenditure in waste management. As per CPHEEO (2000) staff requirement for maintenance of vehicles would vary as depicted in Fig. 1.27. As shown in the figure expenditure towards maintenance will vary depending on the vehicles deployed for solid waste management. There will be need for additional specialised staff stores clerk and maintenance in-charge at the level of 50 vehicle. Deployment of more vehicles would require more staff. There is also requirement of 30 % extra number of vehicles as standby vehicles in order to replace vehicles which may breakdown or meet with accident.

Economics of solid waste can be made profitable with resource recovery and improving traditional waste collection. Copying models from other countries would only make waste management costlier. Use of unsophisticated waste collection vehicle (like bicycle shown in Fig. 1.28) will not only save cost it will be eco-friendly as well as there would be reduction in carbon generation.

Waste minimisation could achieve benefits listed below:

- Recycling revenue;
- Increased profit;
- Reduced raw material costs;
- Reduced energy costs;
- Increased productivity; and

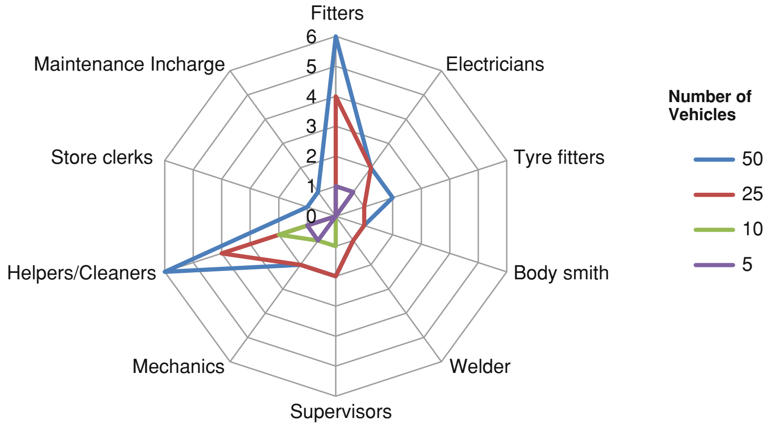


Fig. 1.27 Typical staff requirement for maintenance of vehicle

Fig. 1.28 Unsophisticated waste collection is sometimes economical and efficient as well

- Cost avoidance.

Sophistication of solid waste like using sweeping vehicles as shown in Fig. 1.29 may result in unemployment and demand investment. The presence of slaughter houses in the residential area and commercial areas (Fig. 1.30) would pose greater health risk if not properly managed and hence shifting these sources of infectious waste would be more prudent rather shifting the waste.

Any project or plan would be successful only when it is assisted with proper finance. But financing solid waste should not burden the urban dwellers of any country. The financial issues should be designed in such a way that existing system continue to exist with improved efficiency. Financial issues have been the main cause of poor waste management in many countries. It is estimated that the urban areas of Asia will spend about US$47 billion in 2025. In spite of such expenditure the area still faces problem of waste disposal.

Fig. 1.29 Sophisticated waste collection like road sweeping vehicle may turn out be costly and take away existing jobs

Fig. 1.30 Places like the butcher houses shown may function only few hours but result in waste with high microbial content requiring proper disposal

Many of the solid waste management would end up in dumping waste in outskirts leading to impact on environment. Such practice would add to the financial burden to a country due to increase in disease burden to country by increasing treatment cost and lost manpower by sick people.

1.11.1 Capital Investment

The waste management requires capital investment towards vehicles and infrastructure which could be attained by following means:

(a) **Government Grant/Foreign Aid:** Government grant or foreign aid is one of the several modes by which local bodies responsible for disposing waste is met. Disadvantage of foreign aid is most of the money given as grant or loan will be routed back to country of origin through consultants and equipment suppliers of the country lending/granting the funds. In some such cases the solution provided by the consultants may not serve the purpose at all and equipment may be kept unused due to incapability to maintain them by recipients of aid. Some of the international aid in the past includes the metropolitan environmental improvement programme (MEIP) of World Bank, Sustainable cities programme of united nations environment programme (UNEP) and UN-Habitat, and assistance of canadian international development agency (CIDA) improved solid waste management in some of cities in Asia (UN-Habitat 2010a).

(b) **Incentives:** Incentives are provided in the form of tax credits/waiver towards importing equipment, vehicle etc. Incentives can also be provided in the form of subsidy where in part of expenditure/investment is born by government.

(c) **Budgetary provision:** Local bodies like municipalities can make provision towards capital expenditure by making provision in annual budget and recover the same by increasing local tax. Industries and institutions can make provisions during planning stage of industry/institution so that financial arrangement is made during initial stage of the project.

1.11.2 Operation and Maintenance

Capital investment is not sufficient to lift and dispose the waste without harming the environment and people. The funds towards operation and maintenance can be achieved by means of instruments discussed in the subsequent paragraphs.

(a) **User or Waste-end Fees:** These fees are based on quantum of waste generated. Canberra, Tokyo and Seoul have successfully implemented kerb side charging schemes.

(b) **Waste Disposal Fees:** These are fees payable for disposal of waste at dumping grounds, landfill sites, incinerators or other disposal facility. Some countries such as Australia, Japan and Singapore successfully adopted such fee schemes. Private operators of disposal facility may also charge transportation fee as well if he takes the responsibility to transport the waste.

(c) **Deposit-Refund System (DRS):** In this system a consumer has to pay a deposit at the time of purchase of an item which is usually a part of the merchandise price. The consumer will be given a refund when the waste product, such as empty bottles/container, is returned to the seller or to an authorized recycling/reuse centre. A glass bottle deposit refund was set at Australia, at a rate of between 10 and 15 % of the value of the. In many cases customers throw away the waste items in spite of such refunds which will be picked and sold by waste-pickers.

(d) **Disincentives:** Disincentives are methods to discourage the discard of wastes into the environment. In this practice tax benefits could be extended to persons/organisations who discard waste properly and impose additional tax for others who do not discard at all.

Table 1.2 Income level and waste generation

Income level	Example	Waste generation (kg/person/d)
Income lesser than price of nutritional requisite of family	Rag pickers, beggars, Agricultural labours	0–0.01
Income equal to cost of nutritional requisite family	Agricultural labours, micro entrepreneurs	0–0.1
Income exceeds nutritional requisite and afford minimum clothing	Household servants, labours in unorganised sectors	0.1–0.5
Income exceeds nutritional requisite and can afford minimum clothing and medicine	Servants in restaurants and unorganised sectors	0.5 –1.0
Income exceeds nutritional requisite and afford clothing, medicine, low cost housing and public transportation	Farmer with low land ownership, fishing community	1.0–5.0
Can afford housing, private transportation. Has sufficient savings and disposable income. Travels few times to far away destination in a year	People in organised sector	5.0–10.0
Can afford housing, private transportation. Hash high savings and disposable income. Travels once in month for fun. Travels once or twice to far away destination in a month for business and fun	Entrepreneurs, sports personality	10.0–20.0
Owns house in more than one place/country, private transportation, with very high savings disposable income. Travels extensively every week	High income entrepreneurs, politicians, sports personality, movie actors	>20.0

(e) **Pollution Fines:** Such practice is imposed by collecting fine by a person who is indiscriminately discarding the waste harming environment and causing inconvenience to others.

1.12 Waste Generation: Rich Vs Poor

Waste-generation can be correlated to indicators of affluence, energy consumption and final consumption (Bingemer and Crutzen 1987; Rathje et al. 1992a; Richards 1989; Mertins et al. 1999; US EPA 1999; Bogner and Matthews 2003; OECD 2004). In the past few years, solid waste management in the world has involved complex and multifaceted trade-offs amid an excess of economic instruments, technological alternatives and regulatory frameworks resulting in a variety of environmental, economic, and regulatory impacts in waste management which not only complicate policy analysis but also reshape the model of global sustainable development. As evident from Table 1.2 most of the wastes in the world is generated from rich people. But ultimately the burden and impact is felt by all the people across the world.

Fig. 1.31 Solid waste management should just not end up in cleaning urban area but it should conclude in safe disposal of waste at disposal points too

1.13 Psychology and Waste Generation

The waste disposal on streets which were practiced two generations back in most of the now developed courtiers are now practiced in many developing countries (Fig. 1.31). As per John (2008) unconscious mind is not the exception but is the rule. As demonstrated in Fig. 1.32 the same object can be viewed differently by two individuals with different mindset and person takes immediate decision to discard any substance which is registered as waste in his/her unconscious mind. Psychology and mindset of people varies from one place to other place, one religion to other religion, and one country to other country. People show inhibition to use waste bins in most of the developing nations and through waste on street or the point of generation itself. On the other hand throwing waste outside waste bin is considered uncivilised among most of the people from the developed world. Such mindset has come as a result of long history of proper implementation of legislation in the developed countries and registration of attitude in unconscious mind.

On the basis of a survey applying structural equation modelling it was observed that many factors like concern for the community, self-efficacy, moral norm, attitude, situation factor, and knowledge about environmental harms influenced household recycling behaviour (Zhongjun 2010). Some studies revealed that the young and well-educated people show most concern for the environment (Buttel and Flinn 1974, 1978).

Substantial research exists regarding the recycling behaviour of individuals (Coggins 1994; McDonald and Ball 1998; Schultz et al. 1995; Thogersen 1994, 1996; Tucker 1998, 1999). Several theorists have hypothesized that the conscious minds do not origin from our behaviour; but, they theorize that desire to act are unconsciously triggered and consciousness acts as gatekeeper and sense maker following the fact (Gazzaniga 1985; James 1890; Libet 1986; Wegner 2002).

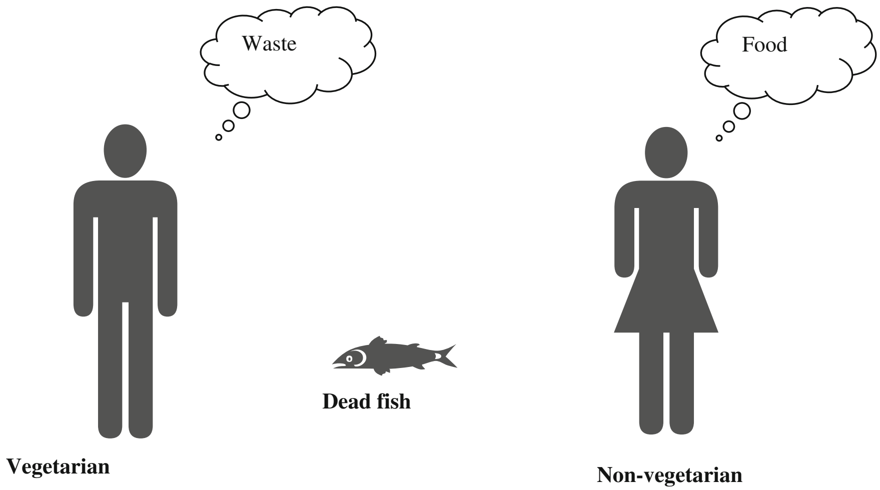


Fig. 1.32 Same object can be identified differently by unconscious mind of individual persons

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Chapter 2
Waste Quantities and Characteristics

Waste management is one of the important services provided by most urban authorities. Solid wastes need to be characterized by sources, generation rates, types of wastes produced, and composition in order to monitor and control prevailing waste management systems while improving the existing system. These data will help to make financial, regulatory and institutional decisions. But population explosion and invention of new materials have kept the quantitities and characteristics changing every day. As per the conservative estimation done by the World Bank in 1999, the municipal solid waste (MSW) from urban areas of Asia would raise from 760,000 tonnes/day in 1999 to 1.8 million tonnes/day in 2025. With the increasing income in the countries of Asia, the solid waste management would be more challenging in the coming days in the continent.

New products wrapped with new packaging materials, new living standards and expectancy, change in income and life style practiced by the affluent people have increased global waste quantity. But as would be discussed in subsequent sections the per capita waste quantity would start declining after it reaches a maximum which is specific to a country or region. This could be due to change in technology which would decrease the waste generation or change in the attitude of people or change in the purchase power or drop in the demand of the product. The USA which has the maximum cars per thousand people in the world would obviously generate less cars and wastes from car manufacturing compared to India and China, where there is more aspiration among the people to own private transport.

MSW includes wastes produced from commercial, domestic, industrial, institutional, demolition, construction and municipal services. But the data pertaining to MSW vary greatly among the waste studies. Usually waste management decisions are based on house-hold waste, which constitutes a small portion of the total waste stream. Further, industries and commercial activity hide the information to avoid statutory obligations.

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2.1 Sources of Solid Waste

Solid waste sources could be urban or rural area. While rural area generates waste which is often organic rich and easily biodegradable the urban waste is characterized by culture and practices of society.

Different countries adopt different categorisation for statutory requirement. For example, solid waste in Singapore is categorised into three major categories (Low 1990): (1) domestic refuse (solid waste generated by markets, food centres, households and commercial premises etc.), (2) industrial refuse (does not include hazardous and toxic waste which requires special treatment, handling and disposal), (3) institutional solid waste (solid waste from government offices, schools, hospitals, recreational facilities etc.).

Figure 2.1 shows some major sources of solid waste. Industries often struggle to increase profit and reduce waste. Manufacturing sector generates MSW from offices and canteens as well as industrial wastes from manufacturing activities some of which are hazardous. Small workshops spread across the urban/rural area as well as along the highways generate both municipal and hazardous waste which requires treatment and disposal differentially. Healthcare establishments like hospitals, clinic, veterinary institutions, blood banks, pathological laboratories, diagnostic centres, artificial insemination centres, clinical research centres have multiplied in all countries over the years to generate MSW as well infectious/chemical/radioactive and sharps. Construction and demolition sites also produce some MSW like food and office wastes, along with construction and demolition wastes. Households produce construction and demolition wastes during repairs and refurbishment. Residences and commercials activities also generate 'household hazardous wastes' like pesticides, batteries, and discarded medicines. Some cities in the developed nations have waste management systems for each of these categories like hazardous, MSW, infectious separately. Activities like agricultural, mining, and quarrying will generate MSW and non-municipal waste streams.

Treatment of wastewater produces a semisolid, nutrient-rich sludge which is often referred as biosolids. It can be recycled and used to improve soil nutrition of crop land. Biosolids contain about 93–98 % water.

2.2 Quantities and Composition

Managing solid waste is one of the most essential services which often fails due to rapid urbanization along with changes in the waste quantity and composition. Quantity and composition vary from country to country making them difficult to adopt for waste management system which may be successful at other places.

Quantity and composition of solid waste vary from place to place as pictorially explained in Figs. 2.2 and 2.3. The municipal solid waste characteristics and quantity is a function of the lifestyle and living standard of the region's

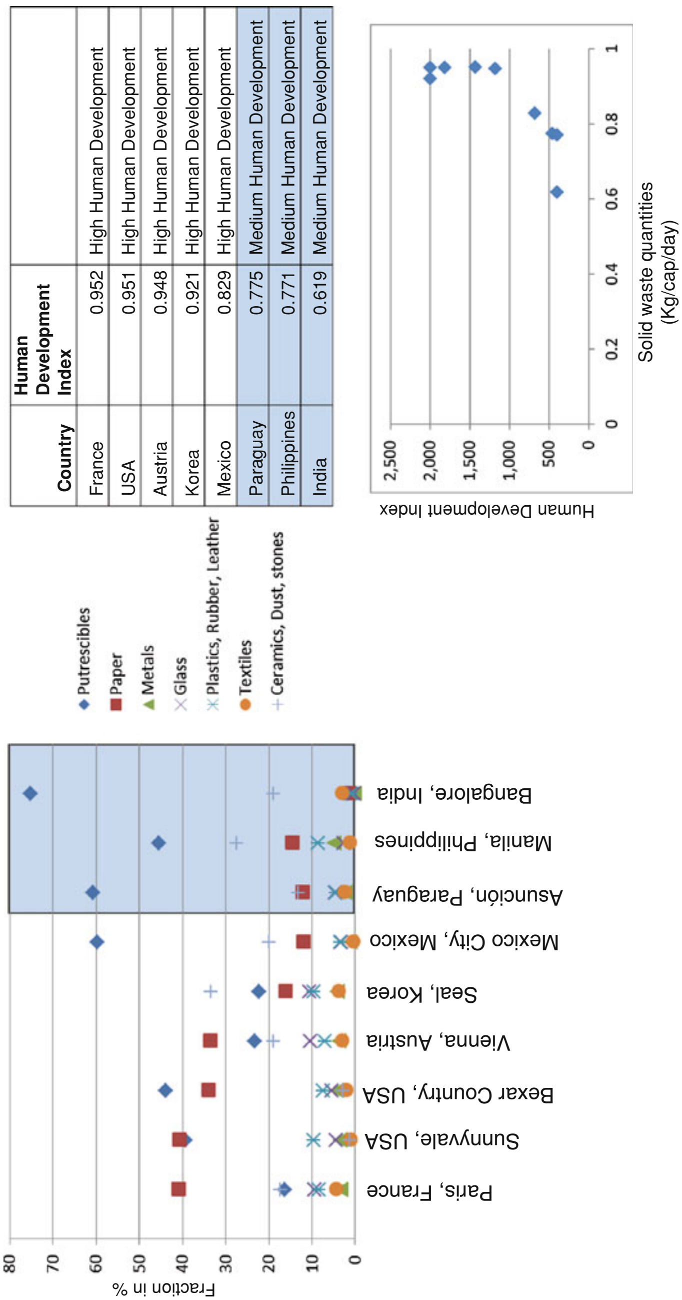
Residential		Waste composes of decomposable food waste, packaging material comprising paper, plastic, old cloth, hazardous waste like old battery, nail polish bottles, insecticides, after shaving lotion, bottle, and biomedical waste like sanitary napkin. Waste quantity varies depending on income and development of the country.
Commercial		Waste composes of decomposable food waste, packaging material comprising paper, plastic, hazardous waste include used batteries, chemical containers. Waste quantity varies depending on the activities and turnover.
Gardens		Waste predominantly composes of garden trimming and leaves. Hazardous chemicals include packaging material of agro chemicals. The waste cold include packaging material like cover used for chips, ice cream cups etc.
Industrial		Waste depends of product of the industry. Industrial waste comprises highly hazardous chemicals to non hazardous packaging material. Quantity of waste depends on quantity and type of product manufactured.
Agriculture and Rural		Waste mainly comprises of rotten vegetable, fruits, leaves and other plant parts. Hazardous chemicals include packaging material of agrochemicals. Most of the waste will be used within the same farm/estate hence quantity is negligible.
Demolition and Construction		Waste mainly comprises of concrete, brick pieces, soil, wood, metals, and other debris. Recyclables material like steel and other metals are recovered by construction/demolition agencies. The quantity depends on size of construction/demolition and construction technology.

Fig. 2.1 Sources of solid waste

inhabitants. Figure 2.2 provides brief analyses of comparison of waste from differing culture and development. Other studies reveal that 60–70 % of waste from Ghana is organic (Carboo 2006; Fobil 2002; Hogaarh 2008). Within the available data, waste from high human development show higher fraction of non-degradable

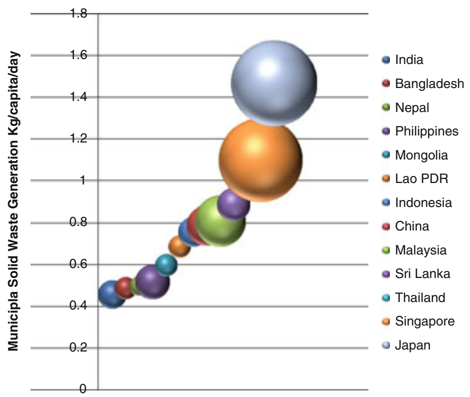
Transportation		This category can be included as subcategory of commercial activity. While developed countries do not generate waste along roads and railway tracks. But people throw waste all along roads and railway tracks in developing world. The quantity of solid waste besides railway track depends on the traffic and number of passengers travelled.
Water and Wastewater Treatment Plants		These plants generate hazardous and nonhazardous sledges and packing material. Quantity of solid waste depends on the quality/quantity of water/wastewater treated.
Beaches and Recreation areas		This category mainly contains litters of food wrappers made up of paper, plastic, metal and glass. Quantity of waste depends on number of visitiors.
Slum		Slum people generate least quantity among all urban sectors. Since the dwellers are poor they make use of the materials available to maximum extent and sell recyclable fraction. Many of the dwellers depend on waste for livelihood. The waste mainly contains ash and decries which does not have recyclable value.
Fruits and Vegetable Market		Fruits and vegetable market prominently contains decomposable waste like rotten and damaged fruits and vegetables. A small percentage of packaging like cardboard, plastic and paper may be present in the waste. Citrus and other sour fruits like pine apple may add to acidity of the waste.
Slaughter House		Waste mainly comprises of hide, hair, undigested and digested food, bones, and meat. The waste is highly putricible in nature and likely to have pathogens that could cause zonoses.

Fig. 2.1 Sources of solid waste (Continued)



Country	Human Development Index	
France	0.952	High Human Development
USA	0.951	High Human Development
Austria	0.948	High Human Development
Korea	0.921	High Human Development
Mexico	0.829	High Human Development
Paraguay	0.775	Medium Human Development
Philippines	0.771	Medium Human Development
India	0.619	Medium Human Development

Fig. 2.2 Solid waste quantities, characteristics and human value indices. *Source* Based on previously reported data (Na th 1993; Diaz, 1985; JICA 1985; Scharff, 1994; CalRecovery, 1992, 1993; UNDP, 2007). Solid waste quantities (Kg/cap/day)



Country	Municipal Solid Waste Generation (kg/capita/day)	GDP Per capita (2005 US $)
India	0.46	3452
Bangladesh	0.49	2053
Nepal	0.5	1550
Philippines	0.52	5137
Mongolia	0.6	2107
Lao PDR	0.69	2039
Indonesia	0.76	3843
China	0.79	6757
Malaysia	0.81	10882
Sri Lanka	0.89	4595
Thailand	1.1	8677
Singapore	1.1	29663
Japan	1.47	31267

Source : World Bank 1999, UNDP, 2007

Fig. 2.3 Municipal solid waste generation vs. income

waste comparable to medium human development. The reason for such fraction is due to high spending of rich countries on packaging material, absence of rag picking, and low number of scrap dealers, etc.

The developing countries use newspaper and other unsoiled paper for packaging including food item. It is not uncommon to see restaurants and road side merchants packing food items, fruits and vegetables in newspapers and covers made-up of newspapers. The number of old scrap merchants in India is high and house and offices sell old paper to these dealers. These dealers in turn sell them to recyclers and other end users. The huge number of rag pickers is one of the reasons for very low amounts of paper, plastic, glass and metals in the wastes. Rag pickers can be seen at residential, commercial, industrial and waste dump areas trying to pick all recyclable fractions of waste.

The people in the developed countries are expected to have higher income jobs and hence there is a general absence of rag picking. The waste papers and old newspapers will be put into trash instead of storing at a point of generation for selling to scrap dealers. On the contrary the developing countries will generate high industrial waste due to the non adoption of waste minimisation technology and weak environmental legislations compared to the developed countries.

The quantity of municipal waste generated from urban settlement is a function of human development index which in turn depends on the life expectancy, gross domestic product and education indices. The quantity of municipal solid waste is invariably higher in the developed nations compared to the developing nations.

Typical waste characteristics of the developing nations are (1) high waste densities, (2) high moisture contents, (3) large organic fraction, (4) cities with sweeping as well as open ground storage characterized by large amount of dust and dirt.

Compilation and comparison of solid waste generation in large cities of various countries show that waste is generated at the rate of 0.4–0.6 kg/person/day in low-income countries, as compared to 1.1–5.0 kg/person/day in high income countries

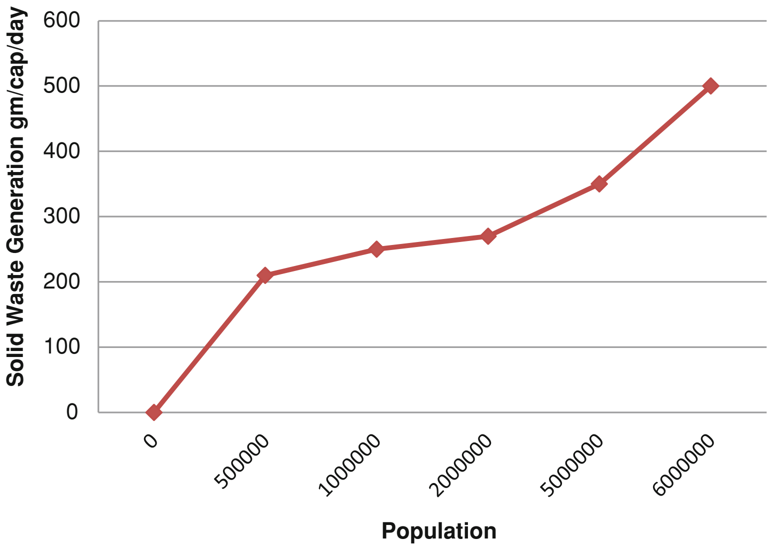


Fig. 2.4 Solid waste generation v/s population of urban settlement in India

and 0.52 and 1.0 kg/person/day in middle-income countries. These figures only indicate the scenarios in larger cities. As expected, the solid waste generation rates become smaller as cities become smaller.

The reason in the variation in waste quantises are mainly due to (1) differences in consumption pattern (people in lower income countries consume less, (2) differences in recycling/reuse at source of generation thus eliminating entry of substance into the waste stream, and (3) differences in culture (high income countries use large quantity of paper for personal hygiene after using toilets).

The following common differences can be observed in the composition of municipal solid waste in the developing countries: (1) waste density of developing nations are 2–3 times more than developed nations, (2) moisture content of developing nations is 2–3 times more than developed nations, (3) waste in developing nations will have large amount of organic waste, dust, (4) waste from developing country is characterized by a large fraction of smaller components (Cointreau 1982; Blight and Mbande 1996).

As per Central Public Health and Environmental Engineering Organisation (CPHEEO 2000) the total solid waste produced per year by 300 million people of urban India was 38 million tonnes. The findings of the National Environmental Engineering Research Institute (NEERI) (1996) with respect to the variations of the MSW generation in India in urban settlements are given in Fig. 2.4. Larger cities generate higher quantities due to the affluence of the city dwellers and higher economic activity.

The total solid waste in Singapore increased three folds in 1999 compared to that of 1980. Domestic solid waste augmented from 0.73 kg/day/person in 1980

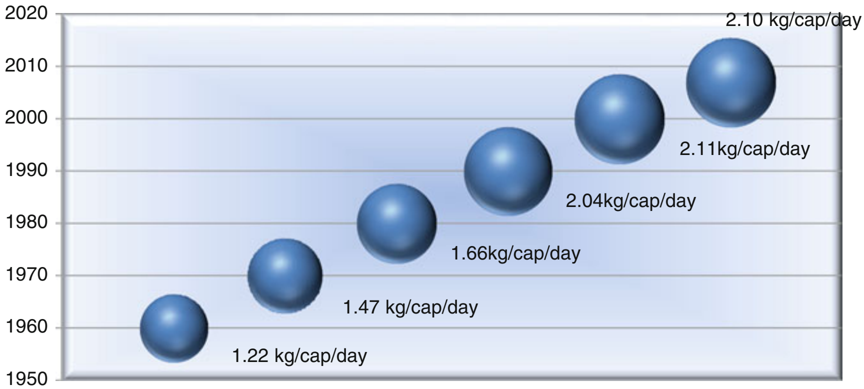
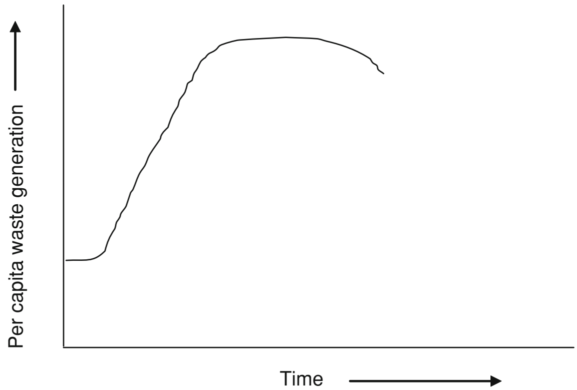


Fig. 2.5 Per capita municipal waste generation in the USA

Fig. 2.6 Variation of per capita municipal waste generation matured economy over time



and 0.96 kg/day/person in 1999 resulting in 640,000 tonnes in 1980 to 1360,000 tonnes in 1999 (Renbi 2002).

Annual MSW generation in the USA has continued to increase from 88 million tons 254.1 million tons in 1960–2007. Findings of the US-EPA (2007) with respect to variation of waste quantities per person is pictorially depicted in Fig. 2.5. As depicted in Fig. 2.5 per capita waste generation varied from 1.22 kg/cap/day in 1960, it grew to 1.66 kg/cap/day in 1980, reached 4.50 kg/cap/day in 1990, and increased to 4.65 kg/cap/day in 2000. Since 2000, MSW generation has remained fairly steady and there is decrease in waste generation in 2007. The trend could follow growth curve discussed shown in Fig. 2.6.

Per capita waste generation ranges between 0.2 and 0.6 kg per day among the Indian city dwellers amounting to about 0.115 million MT of waste per day and 42 million MT annually as on 2006 but this would increase drastically with increase in urbanisation.

The industrial solid waste in Singapore augmented from 207,000 tonnes to 1,538,000 tonnes between 1980 and 1997, followed by a decline by 7.2 % since 1997–1999 (Renbi 2002). About 1.8 million tonnes of solid waste is being recycled since few years (Ministry of Environment 1999, 2000). The institutional solid waste augmented from 94,000 tonnes to 292,000 tonnes between 1980 and 1987 followed by decline to about 6,000 tonnes in 1999 due to waste recycling (Renbi 2002).

The Arab region generates nearly 250,000 tons per day of solid waste with per capita generation of municipal solid waste in some Arab cities, such as Kuwait, and Abu Dhabi, being over 1.5 kg per day (Mostafa and Najib 2008).

Kuala Lumpur, which is a city in a country of transition, generates 3,500 tons/d of domestic and industrial wastes with per capita domestic waste generation approximately 0.8–1.3 kg per day (Abdul 2010). 50 % of the waste generated in Kuala Lumpur is organic (Bavani and Phon 2009). Generation rates in Africa's major cities vary between 0.3 and 1.4 kg per capita per day (Eric 2003). More than 60 % of the urban area is inhabited by low-income citizens in African urban communities making collection difficult (Eric 2003).

As discussed in the earlier paragraphs and figures the waste quantity will increase with an increase in the national income, development, and size of urban settlement. But once the economy of a country reaches maturity in terms of creation of infrastructure, income and jobs there would be steadiness in per capita waste generation thereafter it would decline. The decline in waste generation could also be attributed to technology, regulation, civic responsibility in the society and lower corruption among enforcement agency.

The solid waste generation curve plotted over time would follow pattern of growth curve of a species in given ecosystem. The population of species show low growth during initial state to acclimatize itself to new environment and thereafter there would be speedy increase in population followed by steady phase due to decline in food and other factors. After steady phase there would be decline in population of species. Similarly solid waste quantity would grow up to certain extent and decline thereafter as shown in Fig. 2.6.

While the developed countries are showing growth of less than 3 % in the economy other countries in transition are showing a rapid growth of more than 7 %. Hence there would be more waste generation in countries in transition until people reach a stage wherein there is lesser demand for commodities.

Apart from households, the waste characteristics and quantities vary in airports, railway stations and bus stands, etc. In airports, in addition to the waste from airplanes, solid waste is also produced in airport offices, restaurants, shops, flight kitchens restrooms, maintenance areas, cargo operations, hangars, landscaping, construction and demolition. About 425,000 tons of waste were produced at the US airports in 2004 out of which 75 % of the waste generated is recyclable or compostable (Peter et al. 2006).

Waste from gate areas, ticketing counters and passenger airplanes is called airline waste and usually includes food containers, drink containers, newspapers,

Table 2.1 Waste generation in different category of viewers in a sports event

Sl. No.	Section	Facilities	Waste quantities
1	Very important persons	Complimentary drinks, meals, advertisement material, cheering material.	Two to three kg/ person
2	Elite club	Drinks and eatable on payment. Viewers have to bring own cheering material, banners. Free advertising hand out, caps.	One to two kg/person
3	General class	Drinks and eatables on payment. Viewers have to bring own cheering material, banners. Free advertising hand out paper caps.	Quarter to one kg/ person

uneaten food, magazines, and computer printouts and other papers in ticketing counters.

The quantities and characteristics of waste produced in an airplane depend on length of the flight. The quantity of waste generated in the airports of the US was approximately 1.28 pound per passenger departed in 2004. As per the bstudies conducted by Peter et al. (2006) the airport waste had 20 % compostables, 26 % non-recyclables, 14 % newspaper, 11 % mixed paper, 3 % magazines, 12 % cardboard, 1 % aluminium, 2 % glass bottles, 2 % plastic bottles and 9 % other plastics (packaging, bags, etc.).

The airline industry in the US disposed 9,000 tons of plastic in 2004 (Peter et al. 2006). Similar studies carried out by the Central Pollution Control Board (2009) in India revealed the quantity of plastic waste production form Indian airports to be 4,130 kg per day out of which the amount of plastic bottles was 3,370 kg with per capita plastic waste production at domestic and international airports being 70 and 68 gm, respectively.

Airport can operate with either centralized or decentralized waste management system. Centralized waste management system will have one waste management point for all terminals and airplane waste with the exception of waste from the flight kitchens, which generally manage their own waste. The waste generators are charged based on the quantity of waste generated or included in the lease for tenants or landing fees for airlines.

The quantity of solid waste depends on special occasions like festival, sports events, conferences and elections. Table 2.1 shows waste generation in different category of viewers in a sports event. A typical international sports event is likely to generate about one kg of waste per person entering the stadium. But within the stadium Very Important Persona (VIP) and elite club would generate more waste than other general viewers.

Festivals throughout the world are accompanied by waste generation creating a shock load to existing system. The responsible collection agency would usually collect waste with its existing capacity leaving behind additional burden to be cleared in subsequent days. Apart from festivals other reasons for shock loads will be elections and disasters. Festivals and elections are responsible for increase in quantity by two to ten times the daily average waste. On the other hand disasters can increase waste by 300–500 times the daily average.

2.3 Physical, Chemical and Biological Characteristics

The major physical characteristics measured in waste are: (1) density, (2) size distribution of components, and (3) moisture content. Other characteristics which may be used in making decision about solid waste management are: (1) colour, (2) voids, (3) shape of components, (4) optical property, (5) magnetic properties, and (6) electric properties.

Optical property can be used to segregate opaque materials from transparent substances which would predominately contain glass and plastic. Magnetic separators are designed based on the magnetic characteristics of the waste. Moisture content is essential for leachate calculation and composting. Density is used to assess volume of transportation vehicle and size of the disposal facility. Shape can be used for segregation as flaky substance will behave differently compared to non-flaky substance.

Important chemical properties measured for solid waste are: (1) moisture (water content can change chemical and physical properties), (2) volatile matter, (3) ash, (4) fixed carbon, (5) fusing point of ash, (6) calorific value, (7) percent of carbon, hydrogen, oxygen, sulphur and ash.

Proximate analysis of waste aims to determine moisture, volatile matter, ash and fixed carbon. Ultimate analysis of waste aims to analyse percent of carbon, hydrogen, oxygen, sulphur and ash.

Solid waste production is a function of land use as well as its composition is inversely proportional to the possible soil damage and bacterial contamination of the environment (Achudume and Olawale 2009; Lober 1996; Omuta 1999; Shakibaie et al. 2009).

Wet waste will host more bacteria compared to dry waste. The nutrition in waste also acts as a key factor which decides population balance of species in the waste and immediate environment. Toxic elements discourage multi-cellular organism in the waste. But micro-organisms may still persist at places which may favour some species of micro organism. Saprophytes and fungi will flourish in decomposable matter.

As shown in Fig. 2.7 which is dominated by bottles reveals that physical, chemical and biological characteristics vary hugely from place to place. The collective waste density depends on the fraction of the waste and density of individual waste. Table 2.2 gives proximate analysis and ultimate analysis of various components of waste along with physical properties of the waste.

Fig. 2.7 Physical, chemical and biological characteristics vary hugely from place to place

Proximate analysis is the analysis of waste to determine moisture, volatile matter, ash and fixed carbon. Ultimate analysis is the percent of carbon, hydrogen, oxygen, nitrogen, sulphur and ash. Analysis for solid waste for carbon, hydrogen, nitrogen and sulphur can be done using CHNS analyser (Fig. 2.8). In the absence of such equipment chemical formula for solid waste can be calculated as illustrated in Box 2.1.

Table 2.3 shows the majors living organisms in various solid wastes. Most protozoa feed on bacteria. The free living protozoa can be found in any aerobic environment in which bacteria are present to support their growth. Some of the protozoa are parasitic to humans/animals. Protozoa are primarily aquatic animals but they are also found in solid waste and soil. The ability to form cysts allows them to survive during desiccation and unfavourable conditions. Numerous human diseases are caused by protozoa including *amoebic dysentery*.

Solid waste also hosts substantial amount of fungi. Of about 100,000 species of fungi about 100 are pathogenic to animals and humans (Anthony and Elizabeth, 1981). Gungi causes infection to hair, nail, skin, and lung. Infection occurs by person sores in air which may be present in solid waste. Toxins generated by *Asperigillus flavus* can cause liver cancer and fatty degeneration of liver in people who eat contaminated food.

Some of the bacteria can form spores to allow them to survive when nutrients are not available during dry period. These spores can easily carry away by wind. Contamination of wounds and food by spores of *Clostridium* can lead to fatal consequences. Species such as *C.botulinum* produce toxins which lead to food poisoning. Species such as *C. Persringens,* grow speedily in wounds leading to gangrene (Anthony and Elizabeth 1981).

Waste from slaughter house, fish market and hospital will have abundant pathogens and diverse with respect of species (Fig. 2.9).

Table 2.2 Proximate and ultimate analysis of waste components

Waste material	Waste density (kg/m^3)	Moisture content (%)	Inert residue (%)	Calorific value (kj/Kg)	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Sulphur (%)
Asphalt	680	6–12		17100–18400	83–87	9.9–11	0.2–0.8	0.3–1.1	1.0–5.4
Cardboard, corrugated paper box	30–80	4–10	3–6	16375	44.0	5.9	44.6	0.3	0.2
Brick/Concrete/Tile/dirt	800–1500	6–12	99						
Electronic equipments	105		0–50.8	14116.27–45358.28	38.85–83.10	3.56–14.22	7.46–51.50	0.03–9.95	–
Food waste	120–480	50–80	2–8		48.0	6.4	37.6	2.6	0.4
Garden trimmings	60–225	30–80	2–6	4785–18563	47.8	6.0	38.0	3.4	0.3
Glass	90–260	1–4	99						
Leather	90–450	8–12	8–20		60.0	8.0	11.6	10.0	0.4
Metal–Ferrous	120–1200	2–6	99						
Metal–Non Ferrous	60–240	2–4	99						
Municipal solid waste/biomedical waste	8 7–348	15–40							
Paper	30–130	4–10	6–20	12216–18540	43.5	6.0	44.0	0.3	0.2
Plastic	30–156	1–4	6–20		60.0	7.2	22.8		
Rubber	90–200	1–4	8–20		78.0	10.0		2.0	
Sawdust	250–350			20510	49.0	6.0			0.10
Textile	30–100	6–15	2–4		55.0	6.6	31.2	4.6	0.15
Wood	156–900	15–40	1–2	14,400–17,400	49.5	6.0	42.7	0.2	0.1

Source Tchobanoglaus (1977); Integrated publishing, $NA_{a,\ b}$; Engineering tool box, NA; University of technology Vienna, NA; USEPA, NA; Wess et al. (2004); Othman (2008)

Box 2.1 Chemical formula of solid waste.
Solid waste is mixture of various components which have their own chemical composition and chemical formula. But deriving approximate formula will help calculating oxygen requirement and other probable emission during natural degradation or waste treatment. The procedure for deriving chemical formula is given in following example.

Component	Wet mass in kg	Dry mass in kg	Moisture in kg	Composition in kg					
				C	H	O	N	S	Ash
Food Waste	16	5	11	2.40	0.32	1.88	0.13	0.02	0.26
Paper	46	43	3	18.70	2.58	18.92	0.13	0.08	2.58
Cardboard	11	10	1	4.40	0.59	4.46	0.03	0.02	0.51
Plastic	11	10	1	6.00	0.72	2.38	0.00	0.00	1.00
Total	**84**	**68**	**16**	**31.5**	**4.21**	**27.64**	**0.29**	**0.12**	**4.35**

Step one: Derive ultimate analysis and moisture of individual solid waste components.
Step two: Convert moisture content into Hydrogen and Oxygen.
Hydrogen : (2/18) 16 kg = 1.78 kg.
Oxygen : (16/18) 16 kg = 14.22 kg.
Step three: Revise composition in kg.

C	H	O	N	S	Ash
31.5	5.99	41.86	0.29	0.12	4.35

Step four: Compute molar composition of the waste.
Step five: Compute normalised mole ratio.
Chemical formula of solid waste is $\mathbf{C_{98.26}\ H_{1.57}\ O_{173.96}\ N_{1.05}S}$.

	C	H	O	N	S
Mass, kg	31.50	5.99	41.86	0.29	0.12
Kg/mol	12.01	1.01	16.00	14.01	32.06
Moles	378.32	6.05	669.76	4.06	3.85

	C	H	O	N	S
Moles	378.32	6.05	669.76	4.06	3.85
Mole ratio	98.26	1.57	173.96	1.05	1.00

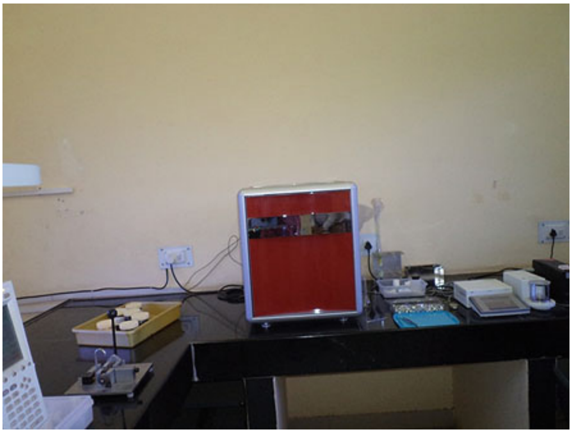


Fig. 2.8 CHNS analyser used for analysis of carbon, hydrogen, nitrogen and sulphur

Table 2.3 Major living organisms present in various solid wastes

Waste category	Fungus	Protozoa	Bacteria	Insect	Rodent
Biomedical waste	✔	✔	✔	✔	✔
Food waste	✔	✔	✔	✔	✔
Hazardous waste					
Municipal solid waste	✔	✔	✔	✔	✔
Radio active waste					
WEEE				✔	✔

Fig. 2.9 Waste from sources like slaughter house would be biologically diverse and dangerous

Solid waste can host an array of insects, arthropod and annelids. The examples of insects include cockroaches, dung beetles, ants, termites, mosquitos, honey bees and house flies. Some of the arthropods in solid waste are spiders and scorpions. Annelids in solid waste include centipede, millipede and earthworm. In some of the waste dumps adjacent to forest area attract wild life as well. While herbivores are attracted towards vegetables and food carnivores are attracted towards hospital waste and other animals which come to eat solid waste. Solid waste dumps attract and host rats, lizards, snakes and street dogs depending on the food available. Due to the absence of agricultural land honey bees in urban area are attracted to left over sweet drinks in trash for collecting nectar.

Micro-organisms play an important role in the decomposition of decomposable fraction of solid waste. Thermophilic bacteria would breakdown of proteins and other easily biodegradable material. Fungi and actinomycetes would degrade complex organic matter like cellulose and lignin. Streptomyces and micromonospora species are commonly observed actinomycetes in compost. Thermonomyces sp., asperigallus and penicillium dupontii fumigatus are common fungi observed in compost. Most of these organisms will be present in municipal solid waste even before composting (CPHEEO 2000).

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Chapter 3
Storage and Collection

Storage is the initial stage immediately after waste generation and collection. Storage can also be made after collection before final disposal or recycle/reuse. In residential neighbourhood solid waste collection frequency may vary from twice a day for a wealthy neighbourhood to once a week for a poor neighbourhood. A slum may not have the service of waste collection at all. Once collected, domestic solid waste is transported to transfer/disposal sites. The vehicles used for this purpose vary from open trucks to compactor trucks with series of small and medium sized vehicles. Industries contract out to private sectors for the collection and transportation to the disposal sites. Most of the metal and packaging materials are sold to scrap dealers recovering part of manufacturing costs.

Since the mid of the 19th century, municipalities have been collecting solid. The major cities in all continents had formal collection services in place for more than a century but with deferring efficiencies. Storage duration depends on the collection frequency. In other words, waste needs to be stored after it has been collected until the next collection. As expected, poor collection system leads to overflow of waste in storage locations. On the other hand, frequent collection reduces economic feasibility of the system. In special cases like infectious waste, it needs to be collected before microbes multiply leading to a spread of infection. In other special circumstances such as disaster prone areas, waste needs to be collected and transported continuously or the waste need to be moved to nearby storage location.

As a precautionary measure prior to *Aero India* 2011, as international exhibition on aerospace, defence and civil aviation, meat stalls and small eateries around the venue of the event were shut down by authorities to avoid menace of scavenger birds which might pose safety concerns to the participants of the exhibition. The organizers also asked concerned authorities to cleanup waste dumped around the venue indiscriminately (The Hindu, 2011). Furthermore, steps were taken to cover wastes in nearby wastes handling facility by gigantic nets to avoid bird menace.

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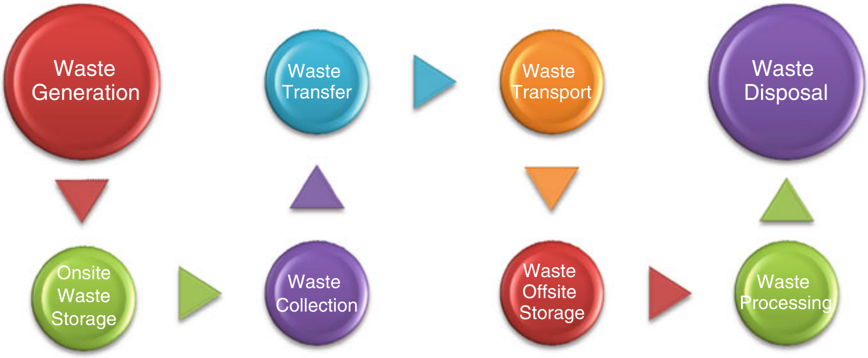

Fig. 3.1 Various stages of solid waste management

Fig. 3.2 Storage without environmental concern

Figure 3.1 shows various stages of a solid waste management system. As evident in the figure, waste storage and collection are important stages where inefficiency of the management may start. Proper onsite storage along with segregation would lessen burden of segregation at the processing stage. Segregation into at the least degradable and non-degradable components would make transportation of degradable waste to composting and non-degradable waste to further categorization or processing. Storage in industry can happen without environmental concern as shown in Fig. 3.2 wherein dust from waste could cause air pollution, reaction within the waste can emit toxic fumes and rainwater can absorb chemicals and carry along into groundwater or surface water. Figure 3.3 shows various examples of storage, collection, transfer and transport.

Onsite storage is often characterized by single bin wherein all of the waste is put for collector to pick up. Many waste-pickers would search these bins to collect what is valuable to them mixing the contents further more. The waste is then collected through small vehicles to be transferred into larger vehicle. The waste in larger vehicle is then hauled to processing followed by disposal or directly to disposal.

Table 3.1 Different categories of storage containers

Capacity	Description	Common usage	Collection methods
85 L	Plastic bin liners	Small business, industry, domestic, public amenities	Liners are deposited directly by hand into collection vehicle
85 L	Rubber/ galvanised steel bins	Domestic, small business, industry public amenities	Bins emptied directly by hand into collection vehicle
120/ 240 L	Mobile refuse bins	Domestic, small business, industry, public amenities	Rear-end loading compactors with lifting equipment
1/2 m^3	Mobile refuse containers	Small business and industry	Rear-end loading compactors with lifting equipment
4–11 m^3	Bulk containers	Large business, industry, garden refuse, construction and demolition waste, public amenities, bulk wastes	Rear-end loading compactors with lifting equipment
15–30 m^3	Open bulk containers	Large business, industry, garden refuse, construction and demolition waste, bulk wastes	Roll-on roll-off vehicles
11, 15 and 35 m^3	Closed containers	Large shopping centres, transfer stations and industries	Roll-on roll-off vehicles

3.1 Storage

There are many designs available for collecting container (Table 3.1). R*ubbish skip* which is a big open-topped container used for loading onto a special type of vehicle instead of being transferred into a waste vehicle onsite. In many places it is used for filling waste by generator or door to door collector. A skip may be replaced by an empty skip. A *dumpster* is a large steel waste container designed to be emptied into solid waste truck. The term is a generalized trademark of the *Dumpster* brand but the term is also common in other places where the *Dumpster* is not an established brand.

As discussed earlier, storage can be either onsite or offsite. Figure 3.4 shows offsite storage of segregated paper waste ready to be dispatched for recycling. While waste protected against wetting due to snow and rain in some countries (Fig. 3.5) to avoid further difficulty in transportation, processing and disposal, waste is piled up openly in developing countries (Fig. 3.6).

3.2 Collection

There are many types of collection practised throughout the world. In Yaounde, Cameroon two types of collection systems are practised: (1) the primary collection and (2) the secondary collection. Primary collection is done at the household level

Fig. 3.3 Examples of onsite storage, offsite storage, collection, transfer, transport

whereas the secondary collection is carried out by the urban council or its contractors. In addition to the primary and secondary collection system (Fig. 3.7) some solid waste management systems can add tertiary collection system to collect waste collected in a secondary waste collection system.

Fig. 3.4 Segregated papers stored for recycling

Fig. 3.5 Waste to be protected from snow and rain at on site storage

Fig. 3.6 Segregated waste piles for recycling

Collection of unsegregated and segregated solid waste is an important part of solid waste management program. Collection starts with the waste bins holding materials that a waste producer has identified as no longer useful and ends with the transportation of wastes to a location for processing, transfer, or disposal.

Most waste collection happens during off-peak traffic hours. In Australia, kerb side collection is the method of collection of waste. All houses in an urban area will have three bins for (1) recyclables, (2) general waste, and (3) garden materials. Also, many households will have compost bins. Some developed countries across the globe convey solid waste via underground vacuum system. In India, curb side collection and door to door collection is the usual method of disposal. In Taipei, waste is collected by the urban council in government issued rubbish bags.

Transport of waste from households, industries, commercial establishments etc., is a growing problem as the rapid urbanization in the developing nations leaves little time for proper layout and planning. Most of the fast growing cities in the developing nations are at the outskirts of existing settlement and waste management is becoming less efficient due to an increase in traffic. UNEP (1996) estimates that up to 70% of vehicles used for collection/transfer in cities of West Africa may be out of function at any one time. No containers are designated in Barbados for waste collection and individual residences have to designate collection container (Headley 1998).

Solid waste collection varies between countries and cities. Some cities like Kinshasa have zero collection of waste. War, mutiny, economic crises or booms, political strife has influence on solid waste generation and management. Huge mounds of solid waste accumulated over the Mogadishu, Somali during civil war (Barise 2001). Even though African cities are using 20–50 % of budget for solid waste management, collection is in the range of only 20–80 %. Corruption often plays a major role in solid waste management. Other factor may also influence,

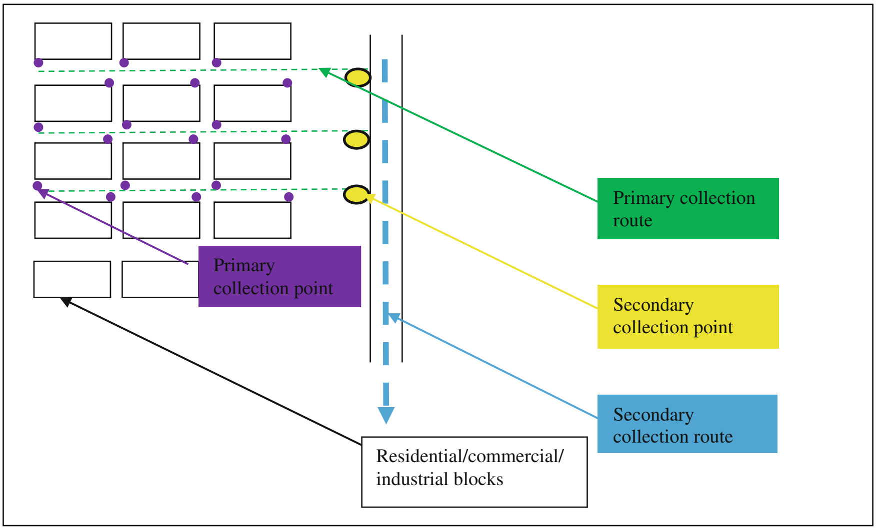

Fig. 3.7 Pictorial depiction of primary and secondary collection system

e.g., soldiers interrupted clean-up activities demanding payment for allowing waste to be removed over the Mogadishu, Somali during their civil war (Barise 2001).

Numerous collection systems have been practised and evolved over time. One of the most primitive system is shown in Fig. 3.8 wherein waste is littered by people haphazardly and collected by service providing agency by sweeping and hand picking. They will be made into heaps or collected in bags/containers which will be transferred to collection vehicle. Such a system may be practiced where there is a lack of civic sense among the citizens. The examples can be mostly observed in developing countries, but some time is visible in the developed countries too.

A fixed bin collection system (Fig. 3.9) is a little better over the litter collection system, where a fixed bin is placed into which people would drop the waste. The leaves and other natural debris would be dropped into this bin. The bin is then manually emptied in a prefixed frequency which may vary from once in a day to once in a week or any other rate. A disadvantage of such a collection system is that the bin would host rodents and dogs if it is not cleared frequently. These bins are constructed at sites of collection or prefabricated depending on the budget available and local knowledge/practice of solid waste management.

India practises a combination of litter collection and fixed bin system. The country showed 70–90 % efficiency in waste collection in major metro cities while in several small cities the efficiency was below 50 %. About 60–70 % of the total expenditure was spent on street sweeping and 20–30 % on transportation. Less than 5 % was spent on the final disposal of waste.

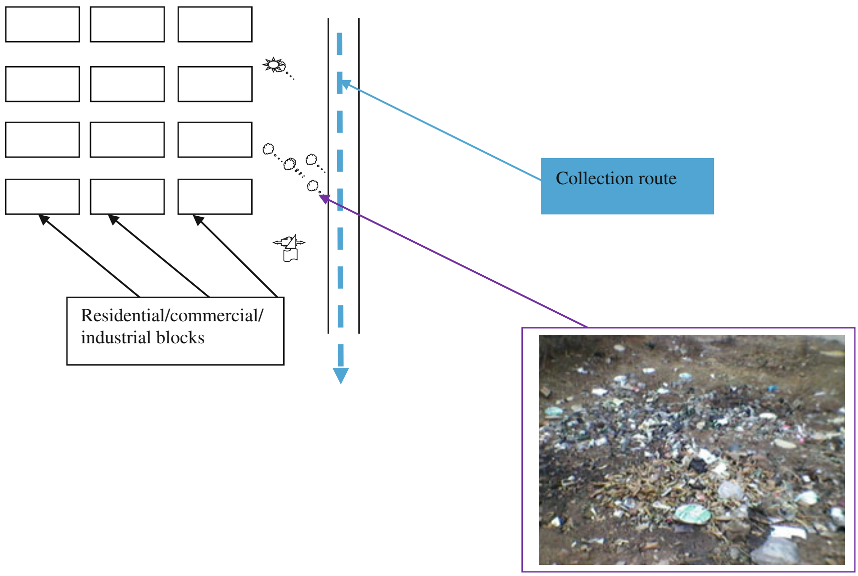

Fig. 3.8 A litter collection system

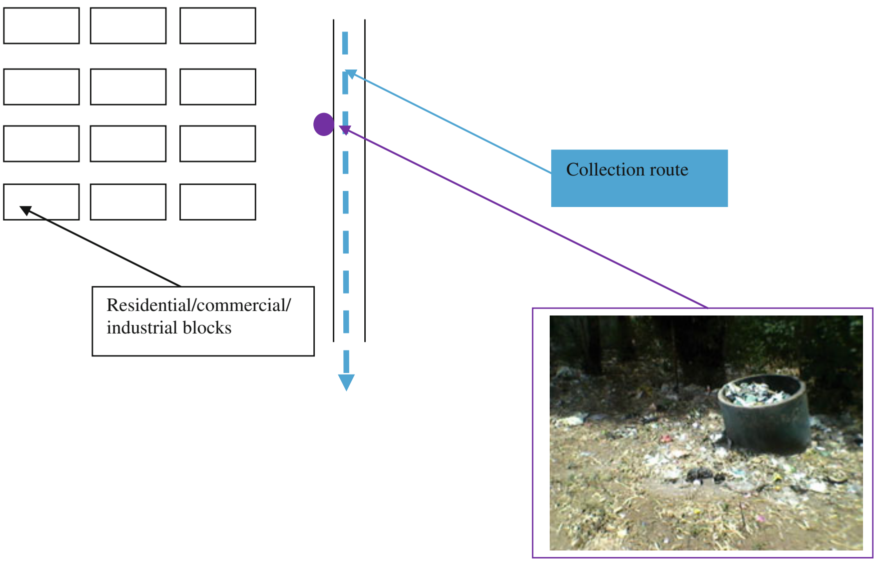

Fig. 3.9 Fixed bin collection system for solid waste

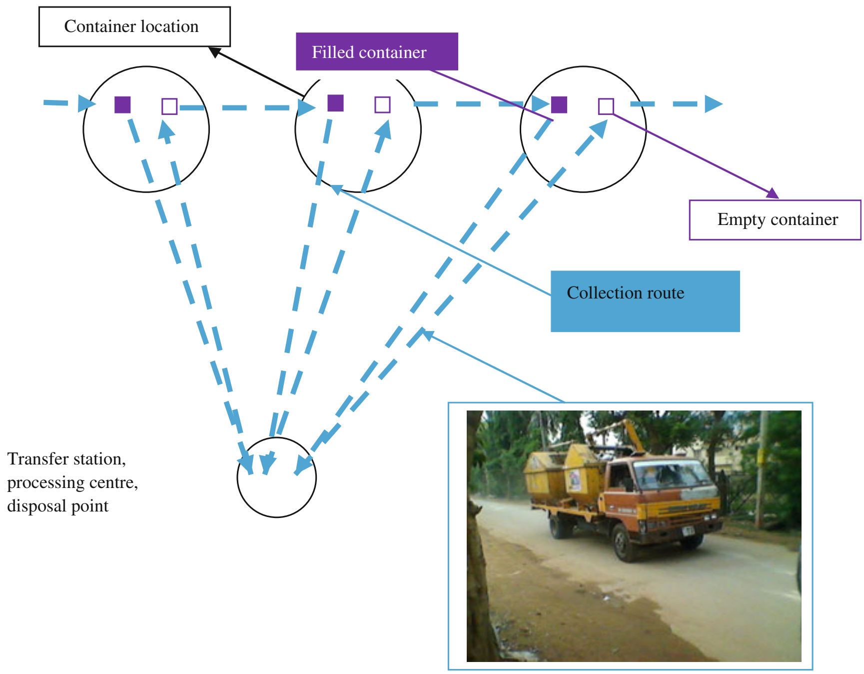

Fig. 3.10 Hauled container system

Figure 3.10 shows a hauled container system wherein the containers filled with waste is hauled to a transfer station or treatment/disposal point. The empty container is placed back in the original position from where it was lifted.

Figure 3.11 shows a stationary container collection system wherein the containers are emptied into a collection vehicle at the point of collection.

Not all type of collection system fall into one of the above discussed system. A combination or stand alone system is practised for construction and demolition of waste, slaughter house waste, WEEE, disaster waste, and radioactive waste where situation would decide the methodology.

The term *collection* includes collection of solid wastes from sources and hauling as well as unloading of these wastes at unloading point (Tchobanoglous et al. 1993). The major types of collection services are: (1) source-separated wastes, and (2) commingled wastes.

Manual methods used for the collection include: (1) the direct lifting and carrying to the collection vehicle, (2) rolling of containers on their rims for emptying to the collection vehicle, and (3) the rolling of containers with wheels to the collection vehicle.

Large containers referred to as *tote containers and* drop cloths called *tarps* are some time used into which wastes from smaller containers will be emptied.

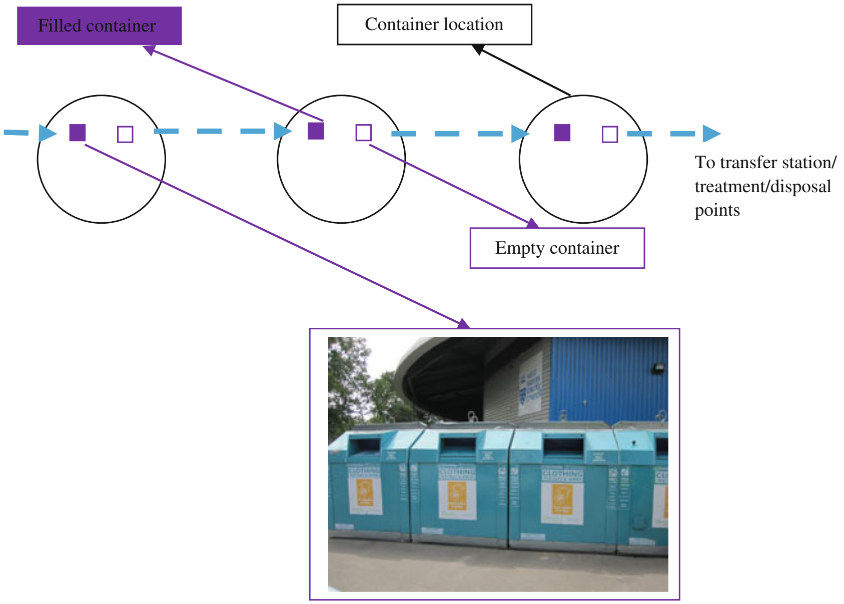

Fig. 3.11 Stationary container system

3.2.1 Collection From Low-Rise Detached Houses

The most familiar types of residential collection services for low-rise detached houses (Fig. 3.12) include (1) curb, (2) alley, (3) setout-setback, (4) door to door collection, (4) setout, and (5) backyard carry.

Where curb service is employed, the home owners shall place the containers with waste at the curb for collection and returning. Alley service is used where alleys are part of the layout of a residential area. In setout-setback service, homeowner will set out the container and collection crew will load the collection vehicle. In case of door to door collection service, the waste generator will hand over the waste to a collector. In setout service a homeowner shall return the containers to a storage location.

3.2.2 Collection From Low and Medium-Rise Apartment

Most of the low and medium rise apartments uses curb side collection service and the maintenance staff will usually transport the containers to curb side collection location.

Fig. 3.12 View of *low* rise detached houses

3.2.3 Collection From High-Rise Apartments

In high-rise apartment, the wastes are collected by building maintenance personnel or wastes are taken to a service area by the tenants or waste will be disposed through chute system. In some countries underground pneumatic transport systems is used along with a chute system.

3.2.4 Collection From Commercial and Industrial Facilities

Solid wastes from commercial and industrial facilities are collected in the lean traffic hours like early morning hours. Waste will be usually stored at a predetermined location for collectors to pick it.

3.2.5 Vehicles for Collection

Almost all forms of vehicles (Fig. 3.13a, b) are used for collecting the waste or materials. Muscle-powered vehicles work well in: (1) densely populated areas with modest street access or unpaved streets, in unlawful residential settlements, on hilly, wet, or rough terrain, and where relatively low volume of waste from a relatively huge number of dense urban settlements (UNEP 1996). The disadvantages of a muscle-powered vehicles are: (1) old-fashioned or shameful, (2) they have limited travelling range and are generally slower compared to fuel-powered

Manual		Manual and simple collection carried out without much investment. It is rather practiced widely by rag-pickers as they cannot afford to buy vehicles.
Push Cart		Push carts are simple to use and can be used almost all sort of road. It could be stopped anywhere to collect waste. It is easy to collect waste littered all around and street sweepings.
Animal Driven Cart		Animal driven cart are widely used in rural area and semi urban area. The multipurpose carts can be easily maintained where there is plenty of food like grass and leaves are available for the animal is without any cost.
Bicycle		Bicycle is widely used by door to door collectors especially in commercial area wherein the recyclable waste can be collected by housekeeping personal of office or commercial establishment.
Tricycle		Tricycle is used where is waste segregation is required and quantity to be collected is too much for a bicycle and too little for motor driven vehicles.
Three Wheeled Automobile		Three wheeled automobile is preferred where too little waste has to be collected from too many pickup points.

Fig. 3.13 Types of collection vehicles

Small Truck		Small trucks are useful inside cities especially in narrow road where large or medium sized trucks cannot move. The trucks can be covered with net or filled with sacks of waste as shown in the picture.
Medium Sized Truck		Medium sized trucks are useful where three to five tons of waste have to be hauled. This is preferred for collection from big shopping complex or office complex.
Truck with Compactor		Truck with compactor needs special maintenance. Preferred if the waste is having low density.
Tractor		Tractors with or without attachment like one shown in picture is commonly used for many years especially if the roads are narrow and is poorly paved / unpaved.
Ship		Ships or boats are used if the waste has be collected across or along the surface water body. If the country or region has well established network of canals which is used for transportation then the ship/boat can replace trucks.

Fig. 3.13 Types of collection vehicles (Continued)

vehicles, (3) weather exposure will have greater effect on humans and animals, (4) the problems of animal temperament, health, etc. (UNEP 1996).

Non compactor trucks used for the transport of goods are widely used in the collection of transported of waste under the following conditions: (1) waste is very wet or dense, (2) labour is relatively inexpensive, (3) there is limited access to skilled maintenance, and (4) collection routes are long and sparsely populated.

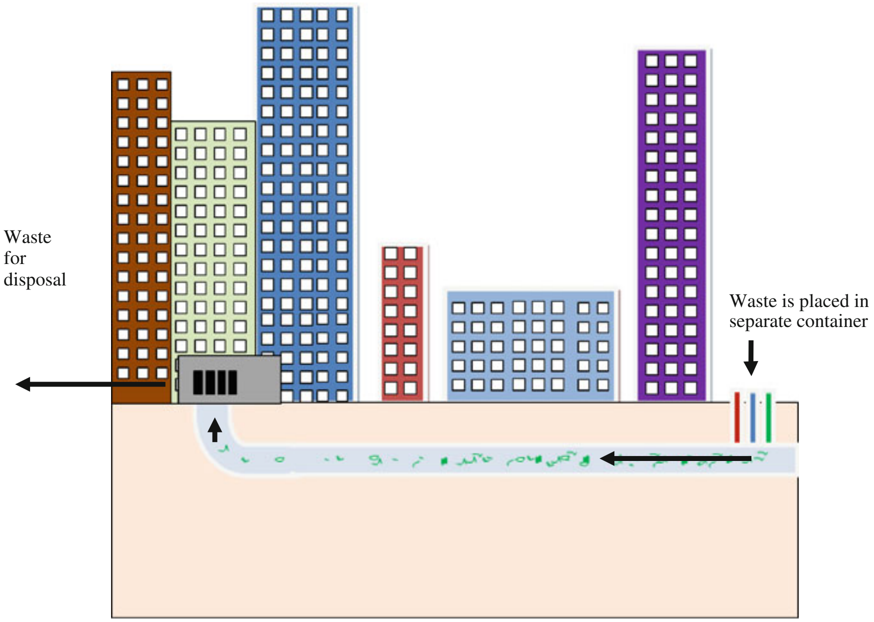

Fig. 3.14 Pneumatic refuse collection system

Compactor trucks are advantageous where paved roads are available and density/moisture of the waste is low. The major disadvantages of these trucks are: (1) government officials feel using compactor trucks as a means to modernization, (2) high initial investment and subsequent maintenance are needed, (3) they need skilled labour for maintenance, (4) spare part may not be available in local market, and (5) waste is wet, greasy and abrasive.

Singapore has direct collection system as well as indirect collection system. In direct collection method waste is collected from individual households. Indirect waste collection has two types of system: (1) in the first type waste is stored in bulk containers in the basement of the apartments which is manually transferred to the bin compounds. From the bin compounds it is later transported to the waste disposal sites, (2) in second type centralized refuse-chute (CRC) is used into which residential waste is discharged from individual flats to the central waste container from where it is transferred to the waste collection vehicle.

Vehicles in some countries are provided with tracking, global positioning system (GPS), geotag, geofence and radio frequency identification (RFID) to efficiently monitor the collection mechanism. The GPS assists a monitoring agency to track the movement of a vehicle on computer monitor from the intermittent signal sent by the vehicle attached with GPS instrument attaché with signal emitting instrument. RFID and georeferences confirm the vehicle has reached the waste container. Geotag provides alerts to the staff in a collection vehicle and monitoring agency.

Fig. 3.15 Transfer station in one of the small cities in India

3.2.6 Pneumatic-Refuse-Collection System

The pneumatic refuse collection (PRC) system (Fig. 3.14) in Singapore introduced in 1998 proved to be costly with capital costs being $2000 per flat and operating costs being $13/flat/month. The CRC system in Singapore has an investment cost of $146 per flat and an operating cost is $3/flat/month (Renbi and Mardina 2002).

3.3 Transfer and Transport

Transfer stations are facilities where waste is transferred from smaller vehicles used for waste collection into bigger vehicles for hauling to a disposal or processing site. The transfer may happen in any of following ways: (1) directly from smaller vehicle to larger vehicles, (2) transferring waste dumped by small vehicles on open space, (3) transferring waste through infrastructure accompanied by some removal, separation, compaction, shredding etc. Vehicles servicing a collection area will travel a shorter distance, unload, and return to collecting the waste.

Transfer station design in developed countries includes a tipping floor serviced by equipment for pushing waste into large vehicles. Waste components which have recyclable values are sorted and processed to recover cost of solid waste management (Fig. 3.15).

There are several type of transfer station designed considering local need and constraints. Some of major types are discussed below:

Open tipping floor	In this type collection trucks un-compacted waste is unloaded onto the tipping floor from where material handling equipment organizes the waste and place it in larger vehicles

Open pit design	In this type of transfer station collecting vehicles dump waste into an open pit from where waste material is mechanically or manually transferred into larger vehicles
Direct transfer stations	In this type wastes from smaller vehicles are directly transferred into larger vehicles
Transfer station with compartment	In this type, compartments are formed in open space or under large structure with roof. Collection vehicle will dump in one of the compartment while waste in the other compartment is segregated, shredded along with other operation. Once the intermediate operations like segregation, shredding etc. are carried out, waste would be loaded into larger vehicles

Most main cities in Africa have an organised municipal waste collection system with collection coverage ranging from 20 to 80 % with a median range of 40–50 % (CalRecovery Inc. and IETC (UNEP International Environmental Technology Centre) 2005). The collection is carried out in many ways including bags carried by humans, human- and animal-drawn carts, bicycles and tricycles, open-back trucks, compactor trucks, and trailers.

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Chapter 4
Materials Recovery and Recycling

Reduce, recycle, reuse and recover are the most important component of solid waste management. In the absence of these components, over a span of time there will be nothing left in the world for further use.

Material recovery practice varies from place to place. As discussed in a previous chapter municipal solid waste could comprise of paper, textile, ceramic, dust stones, leather, metal, glass, food waste and other decomposable organic materials. Countries like the UK, Switzerland, Austria and the Netherlands where key reasons for growing adoption of the 3R (Reduce, Recycle and Reuse) due to a scarcity of landfill capacity or sites. In Japan more than a quarter of a century of research was done on reuse demolished concrete, but relatively small concrete has been recycled due to the non-compliance with the prescribed standards.

In England, shoes, clothes, textiles and accessories which made up 4–5 % of the total domestic waste (DTI 2002) during 2003/2004 used for various purposes. There are about 6,000 banks in the UK out of which 85 % is run by charities to collect used cloths. In 1999 about 43 % went to second hand clothing, 22 % was used as filling materials, 12 % went to wiping cloths and 7 % went to fibre reclamation (Anne et al. 2006).

In the developing world waste recovery and recycling generally happen within a house itself. Many of the carry bags would be reused for filling useful material or waste before discarding them. Tins and jars of food materials would be used for storing groceries in kitchen or as toys for kids. The newspapers would often be used to wipe glass or table tops. Other uses of old paper are packaging or making pulp for manufacturing cardboard/paper.

Food wastes from restaurants are usually used for feeding cattles. Waste from slaughterhouse is used for dog biscuits or composting. The waste fish is often used for manufacturing poultry feed, while plastic material in recent days is used for mixing with bitumen while laying pavement to roads. Plastic can also be melted and remolded. If the organic material cannot be used as food it could be converted into energy.

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Fig. 4.1 Sophisticated waste reception at a waste processing plant

Dust and rubles can be used for making building blocks. The metallic component has huge demand all over the world due to its readily available market. The metallic component would be melted and remolded. Another option available for organic fraction waste is energy recovery by either incineration or another technique like pyrolysis.

Other major component namely glass can be melted for remolding. In many cases used bottles are washed and reused. But 100 % reuse and recycling is still not achieved by any country. Material recovery and recycling facilities could be sophisticated with highly organized reception centre as shown in Fig. 4.1 or could be just a place under trees.

Box 4.1 Zabbaleen.
The Zabbaleen (means "Garbage people" in Egyptian Arabic) have served as Cairo's informal garbage collectors since around 70–80 years. Spread out in seven different settlements in the Greater Cairo Urban Region with largest settlement being Mokattam village, nicknamed as "Garbage City". Migrants from the "Wahy" oases called Waheyya came to Cairo to collect the waste at the beginning of the last century, who received remunerations for the garbage collection. During 1930–1940s, new migrants from Upper Egypt came to Cairo in order to breed pigs on waste and started waste collection by signing contracts with the *Waheyya* (Lise 2010).

Informal recyclers often originate from social groups or belong to minorities. Examples of which include the Zabbaleen (Box 4.1) in Egypt, Basuriegos, Cartoneros, Traperos and Chatarreros in Colombia, Chamberos in Ecuador, Pepenadores, Catroneros and Buscabotes in Mexico, Buzos in Costa Rica and Cirujas in Argentina (Medina and Dows 2000; Berthier 2003). In a many countries the informal sector provides a waste collection service where there is no formal waste

Fig. 4.2 Waste segregation at point of collection

collection system in place (Coad 2003; Haan et al. 1998; Scheinberg 2001) with prime economic motivation being income that can be made by recycling the collected waste.

4.1 Segregation

Segregation of solid waste is carried out at: (1) source (residences, operation theatre, industries etc.), (2) the collection point (Figs. 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9), (3) transportation, (4) disposal point. It is at most important that non degradable fraction of solid wastes are segregated so as to carryout major biological processes enlisted in Fig. 4.10. The major segregation can happen at the point of collection itself.

In some places waste is usually packed in covers and thrown into bins meant for it. The segregation done at a collection point often generates additional income for waste collectors wherein the collectors usually keep papers, undamaged bottles, metal and plastic items separately for selling to scrap dealers.

Repeated segregations up to a maximum extent as demanded by market are practised in several parts of India where labour is available in abundance. This system basically works on the principle of segregation at every level. The degradable waste from residential and commercial areas is collected separately to avoid soiling of non-degradable waste which would reduce price during selling. The non degradable waste is segregated into different components. Materials like electric wire, which have copper as one of their components, will fetch higher value compared to others but the quantity might be very less requiring long accumulation period. Materials like paper or plastic cover may fetch lower cost but the quantity will be sufficient for disposal every day.

The organic waste is converted in useful product designed to generate zero waste at the end of processing. Such practice has been well practised in small self

Fig. 4.3 Segregated waste at zero waste plant where components of waste are segregated to the maximum possible extent

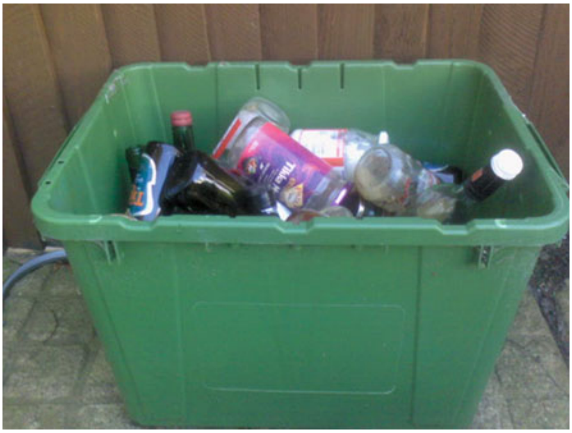

Fig. 4.4 Glass bottles collected in dedicated bin for recycling

Fig. 4.5 Large dedicated containers for collection of bottles

Fig. 4.6 Large dedicated containers for waste recycling

Fig. 4.7 Dedicated containers for collection of garden waste

hep groups across Vellor in India. The system is designed to be self sustainable at the planning stage itself. The waste quantity collected in technical university and large hospital does not require waste generator to pay for the service, while small colonies would be required to pay a nominal fee which may be as small as the cost

Fig. 4.8 Signs for dedicated containers (Fig. 4.9) at an office

Fig. 4.9 Dedicated containers for segregation at source

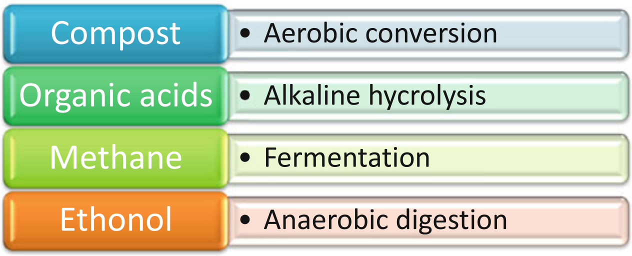

Fig. 4.10 Biological processes for the recovery of conversion products from solid waste

of a banana per month. In some places the service charges are paid by handing over old newspaper received over month to self help group which has huge established market.

The zero waste concepts not only avoid pollution due to incineration and generation of methane/leachate from land fill, but it will also avoid environmental degradation due hauling waste to long distance. The area required depends on the quantity of waste. In practice small processing units are profitable and manageable due to low overhead cost as well as labour problem.

The system shown in Fig. 4.11 is practised in temple, university campus, hospital campus and residential area at Vellore is designed in such a way that the system is profitable. The organic fraction is fed to cattle. The cattle dung is fed to anerobic digester. The anaerobic digester converts dung into biogas and digested sludge which is ready for vermi-compost. The digested cow dung is used as *seed microorganism* to organic waste to speed up the degradation.

Table 4.1 shows example of price of waste components. As could be seen the different quality paper would fetch different price. The mix up of all quality paper would fetch cheapest quality paper. The logic hold good for plastic as well. As could be seen the good quality plastic would cost several times that of poor quality plastic. Hence rag picker always chooses material of higher values living behind huge litter of soiled plastic covers. Reusable material like beer bottle is sold on number basis rather than weight basis. The costly material like copper wire and WEEE is priced high. Prices in Table 4.1 do not make much sense in the developing countries because except for high cost components like metal, segregation of each components would be costly considering cost of manpower which is nearly 40 times higher than developing nations making it disposal in landfill site as the best option.

4.1.1 Hand Sorting

Hand sorting or *picking* is the most widely used method in all over the world. Scavengers all over the world carry out hand sorting after they pick the waste. Figure 4.12 shows waste segregation facility with provision for hand sorting and Fig. 4.13 shows a schematic diagram of hand sorting.

Sorting can be positive sorting or negative sorting. In the positive sorting, personnel will pick what is required from the conveyor belt. In the negative sorting, personnel will pick what is not required.

4.1.2 Screens

Screening is a process in which a series of uniform-sized openings allows separation of material smaller than that of the opening. Most popular screen for processing MSW is the trammel or rotary screen (Fig. 4.14). Diameter of trammel ranges between 0.6 and 3 m. A motor is attached to tromel at one end rotates the drum at about 10–15 r/min.

Another variation of screen is a disk screen (Fig. 4.15) wherein a series of disks mounted on shafts. As the shafts rotate undersized objects fall between the spaces

Fig. 4.11 Zero waste plant

Table 4.1 Example of prices of waste components in 2011 in India

Waste component	Quantity	Price
Aluminium scrap/can	1 kg	75.00
Beer bottle	1 No.	1.50
Broken glass	1 kg	4.00
Brown cartoon box	1 kg	4.50
Coconut shell	1 kg	2.00
Egg shell powder	1 kg	25.00
Glass bottle	1 kg	27.00
Iron scrap	1 kg	9.00
Magazine with good quality paper	1 kg	5.00
Magazine with poor quality paper	1 kg	3.00
Milk cover	1 kg	15.50
Oil cover	1 kg	6.50
Old slipper	1 kg	1.00
Pet bottle	1 kg	1.50
Plastic ice cup	1 kg	1.00
Plastic made up of recycled plastic	1 kg	3.25
Plastic made up of virgin plastic granules	1 kg	15.50
Poly vinyl chloride(PVC)	1 kg	25.00
Used note book	1 kg	9.00
Waste newspaper	1 kg	2.10
White pet bottle	1 kg	1.50

Fig. 4.12 Waste segregation facility with provision for hand sorting

of the disks and are collected in one hopper. The larger objects are carried along and deposited in a second hopper.

Another type of screen called vibrating screen (Fig. 4.16) consists of a flat screen which undergoes reciprocating or gyrating motion. Figure 4.17 shows vibratory screen with electro static separator and collection mechanism in a WEEE processing unit.

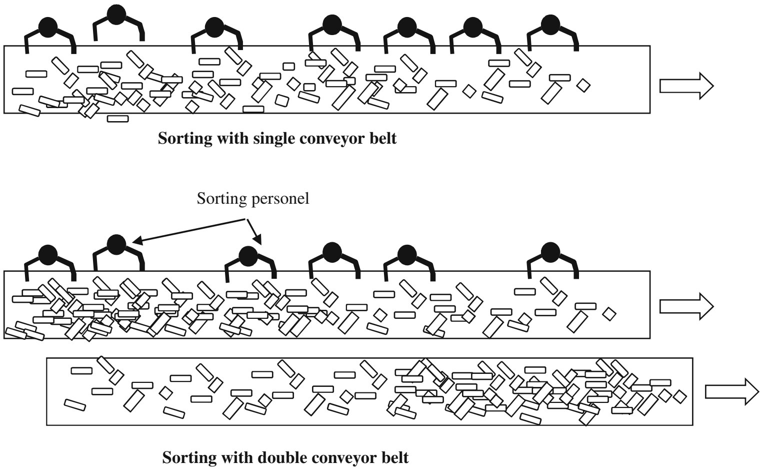

Fig. 4.13 Schematic diagram of hand sorting

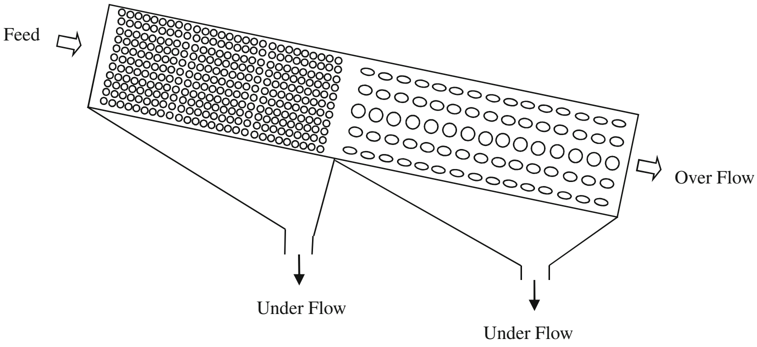

Fig. 4.14 Trommel

4.1.3 Air Classifiers

Air classifiers are used to separate the less dense material from denser fraction using air. In air classifiers less dense objects will be trapped in an upward current of air, while the more dense material will drop down. The less dense material entrapped in the air stream will be separated from the air. Usually, this is done with a *cyclone separator* (Fig. 4.18) *or a*n air knife classifier (Fig. 4.19).

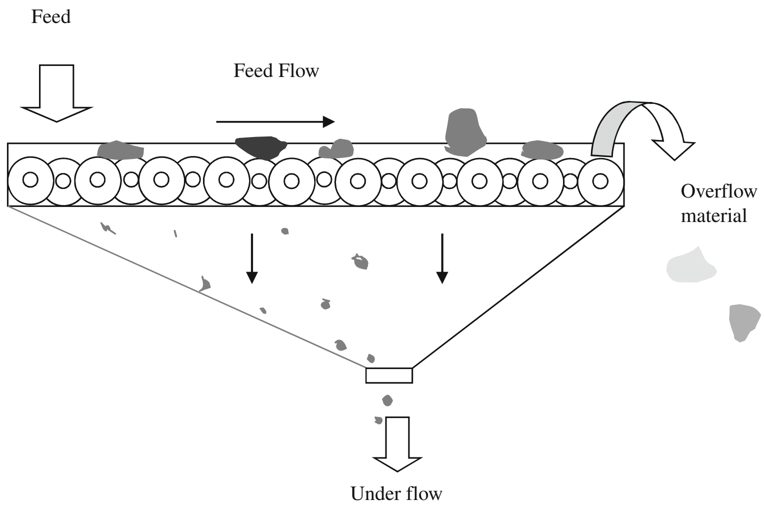

Fig. 4.15 Disc screen

4.1.4 Sink/Float Separators

Sink/float separator are used to separate heavy fraction from lighter fraction in which a fluid is used as media for separation. While the lighter fraction with specific density greater than that of fluid floats the heavier fraction sinks. Common fluids used are: water, water–methanol mixture, sodium chloride solutions and Zinc chloride solutions. Float baths are kept in a series based on specific gravity of materials to be sorted. Pumps are used for circulation and direct the flow. Disadvantage of this method are: (1) requires long retention period for flaky objects to settle, (2) needs wastewater treatment, (3) difficulty in controls as smaller flakes of heavier fraction may float and vice versa, (4) needs wetting of particle in order to avoid attachment of air bubbles to objects and flocculation, (5) density of aqueous solutions vary due to change in ambient temperature and evaporation, and (6) contamination of objects.

4.1.5 Inclined Tables

Inclined tables (Fig. 4.20) are table inclined at an angle convenient for sorting/processing waste. The tables may be provided with conveying belt. *Inclined tables* can be used to separate objects of various densities/sizes by washing down lighter objects down the inclined table along the incline.

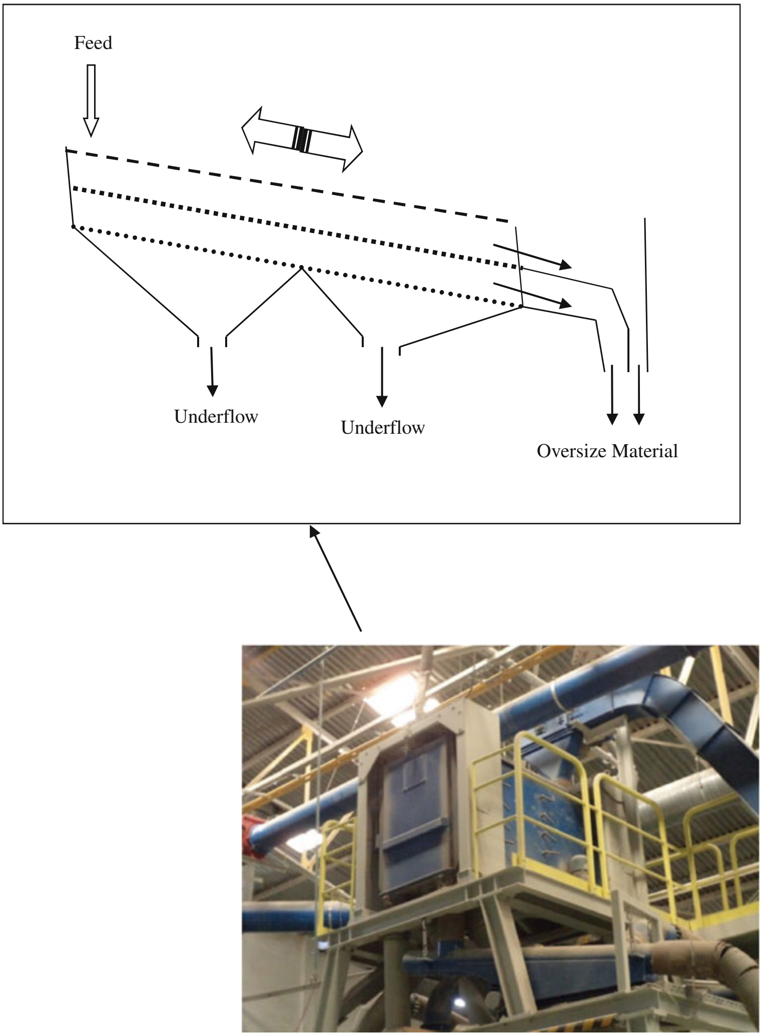

Fig. 4.16 Vibratory screen

4.1.6 Shaking Tables

Shaking tablesare tables shaken with a movement perpendicular to fluid flow. Under the effect of gravity, crosswise running water, inertia and friction, materials are stratified by weight and size.

Fig. 4.17 Vibratory screen with electro static separator and collection mechanism in a WEEE processing unit

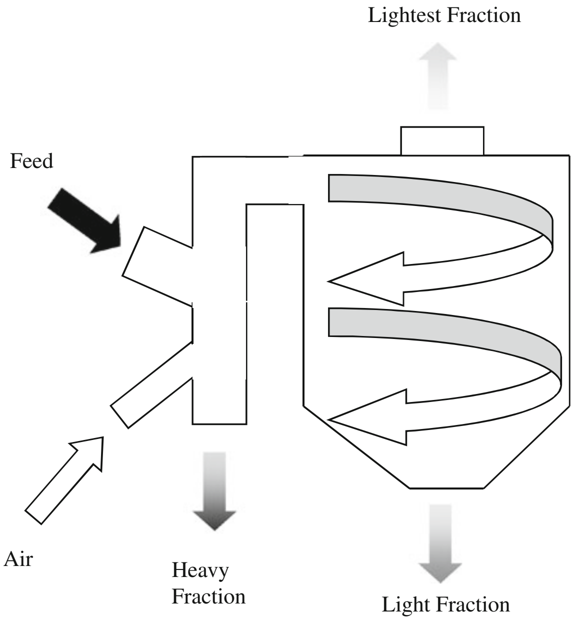

Fig. 4.18 Cyclone waste clessifier

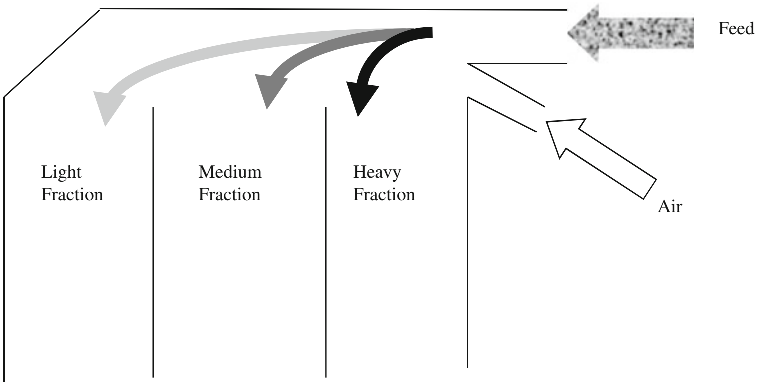

Fig. 4.19 Air knife classifier

Fig. 4.20 Inclined tables

4.1.7 Optical Sorting

The optical sorting can be done for: (1) differently coloured waste bags, (2) different components in waste. In the case of sorting coloured bags, users are provided with different coloured bags. The waste bags are collected and transported to sorting unit where they are transferred to a conveyor belt. The bags are sorted as they move using technology that recognises colour of bag. Automated waste sorting technology uses optical sensors to sort waste usually composed of plastics, paperboard, cans and glass. Sophisticated sorting equipments uses camera capable of recording length, width, area, shape, colour as well as surface structure. The data recorded are compared with objects described in database and ejects selected object as they pass under the camera.

Based on the requirement a range of spectroscopic methods are available for sorting. Examples include infrared spectroscopy, Raman Spectroscopy, laser induced plasma spectroscopy, and laser induced thermal impulse response, sliding spark spectroscopy, X-ray fluorescence spectroscopy.

4.1.8 Sorting by Differential Melting Temperature

This method is used for separation of commingled plastic by using a heated roll/belt separator on which separation takes places by selective thermo adhesion.

4.1.9 Sorting by Selective Dissolution

In this method separation of different material is achieved by selection of solvent and control of temperature. For example, the same solvent can be used for Polypropylene (PP), Polystyrene (PS), LDPE, HDPE and PVC as these materials will dissolve at different temperatures. Advantages of this method is that the recovered plastic is chemically near to the virgin plastic.

4.1.10 Magnetic Separation

Magnets are used to segregate magnetic materials from the other material. A magnet is placed at a strategic location near a conveyor belt, carrying the refuse. Figure 4.21 shows magnetic separator and Fig. 4.22 shows schematic diagram of alternative arrangements that can be adopted for magnetic separation. Materials which are attracted towards magnet are separated from the waste stream.

4.1.11 Eddy Current Separators

Eddy current separators (Fig. 4.23) are used for non-ferrous metals from non-metallic fraction. When a non-ferrous metal, passes above the separator, the magnets in the shell rotate at high velocity resulting in eddy currents in nonferrous metal which in turn creates magnetic field around the nonferrous metal. The polarity of magnetic field will be the same as that of the rotating magnet, causing nonferrous metals to be repelled away from magnet. Such repulsion results in the trajectory of the nonferrous material greater than that of non-metal fraction, allowing the nonferrous and non-metal streams to be separated. The ratio of

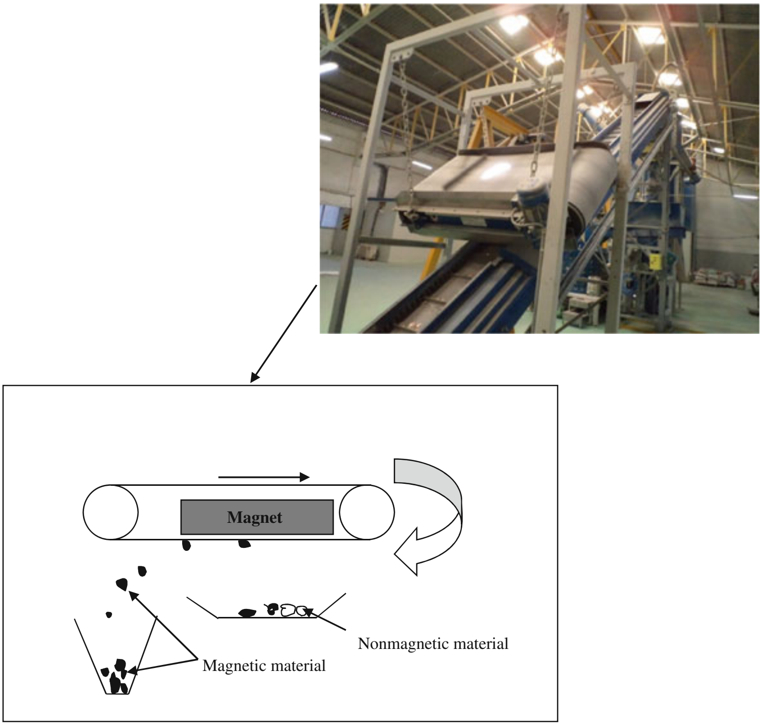

Fig. 4.21 Magnetic separator

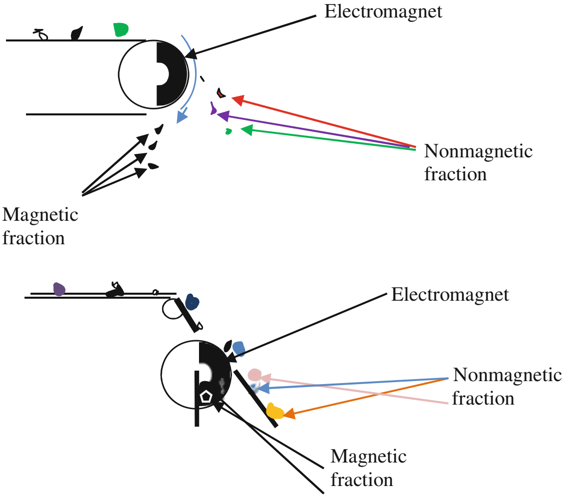

Fig. 4.22 Schematic diagram of alternative arrangements that can be adopted for magnetic separation

electrical conductivity and density of the material is the main criteria for an eddy separation. The materials with higher ratio of conductivity to density will be separated easily compared to those with lower ratios.

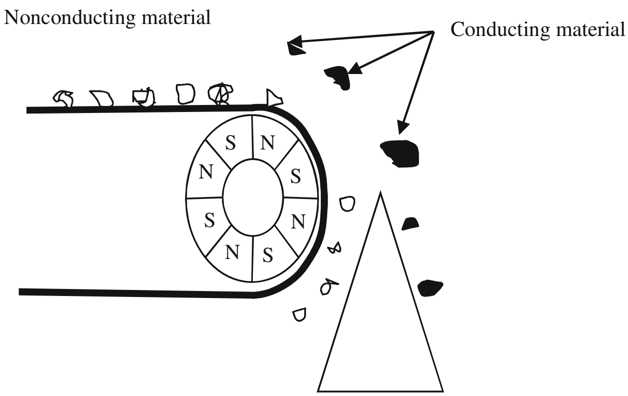

Fig. 4.23 Schematic diagram of eddy current separator

4.1.12 Electrostatic Separators

Electrostatic sorting has been used since the 1970s for sorting mixed plastic waste. In this method plastic material is separated through differences in electrostatic charges in different types of plastic. The materials are sorted by charging the objects and collecting them which rely on the extent of electric charge the materials acquire.

4.1.13 Shredding

Shredding is used for size reduction. There are many types of shredders. Hammer mill shredder consists of a central rotor with pinned radial hammers. Another type of shredder is known as a hog, used in pulp and paper manufacturing is used to shred green waste. Shear shredders are used to slice whole tires. Knife shredder (Fig. 4.24) is used for cutting material into small pieces.

Many shredders are available in the market varying from automobile shredders to paper shredders. The particular shredding process will depend on the material to be shredded. The shredders can be used for Paper, WEEE, vehicle parts, RDF, waste wood etc. Each year, 30 million vehicles are scrapped all over the world (Ahmed 2009) and Auto shredder residue (ASR) arising from shredding of automobiles comprises of heterogeneous mixture of metals, plastics, rubber, glass, wood, dust etc., Rotary shear shredders are the most common pre-shredder used for scrap tires which will have two counter rotating shafts. The shredded tires are further processes by grinding machines to generate granules.

There are two major categories of shredders used for shredding MSW—low speed, high torque (LSHT) shredders and high speed, low torque (HSLT) shredders (hammer mills) (Fig. 4.25).

Fig. 4.24 Knife shredder

Fig. 4.25 *Low* speed, *high* torque shredders

Vertical hammer mill use high speed rotating shafts at 700–1,200 rpm equipped with fixed/pinned hammers. Hammer mills use impact forces to convert waste into smaller particles. Low speed, high torque shredders use shear cutting and tearing forces.

Fig. 4.26 Pulveriser

High-speed impact Horizontal-shafthammermill will comprise feed hopper whrein material is fed to a hammer circle. The hammers, attached to a shaft, impact the feed material, and break it into smaller pieces. Further below the hammer circle will be a series of cast grates, wherein the material is torn between the hammers and the grates, until its size is reduced to pass through the grates.

Vertical-shaft ring grinders are gear-type device which grinds the feed material.

In a flail mill material is fed through a feed chute. The flails are attached to a rotating shaft which function as knives wherein paper is torn and ripped, glass is pulverized into very fine sizes whereas cans pass through the mill relatively unaffected.

A pulverizer utilizes a breaker plate and hammers along with impact bars and impact plates that assist in the pulverization of fragile materials (Fig. 4.26).

A granulator or knife shredder will have long knives for cutting materials into small pieces for later separation.

Paper shredders are used to cut paper into strips or fine particles. Sizes of paper shredders range from few pages to million pages per hour and can be built into a *shredding truck*. Shredder can either electrically powered or hand operated. *Strip-cut* shredders use rotating knives for generating narrow strips. *Cross-cut* shredders use two rotating drums to cut parallelogram/rectangular/rhombus shaped shreds. *Particle-cut* shredders cut paper into tiny pieces. *Cardboard* shredders shred cardboard into strips or a mesh pallet. *Disintegrators* and *granulators* cut the paper at random till the paper pieces are capable of passing through a mesh. In *Pierce and Tear* type of shredder rotating blades pierce and then tear the paper.

4.1.14 Pulping

Waste pulpers are used for grinding organic matter like cardboard, food scraps, and paper, with water. The pulp is then processed to produce dry pulp by removing the moisture content. Capacities of waste pulpers may vary from 125 to 2,000 kg/hr and capable of reducing the waste volume by 70–85 % their by reducing waste transportation costs. The food wastes are segregated from paper and cardboard waste so that pulp from food waste can be used for animal feed. Dry pulp can be mixed with other feed materials.

Waste pulpers are used in educational facilities, restaurants, health care facilities, casinos, cruise ship lines, manufacturing plants, and in-flight kitchens. Pulpers can be used for waste from industries as well.

Food waste pulping facilities will have the potential for foul odour and rodent/pest infestations. Advantages of waste pulping are: (1) reduction in volume of waste, (2) reduction in number of waste pickups, (3) reduction in labour, and (4) Elimination of the need to segregate paper from food waste. Disadvantages include high initial cost and energy costs.

4.1.15 Crushing

Waste crushers can be used for variety of material like bottle, drums, can, cars, concrete, tyre etc. Based on the material to be crushed, crushing equipment is selected. Waste crusher can be mobile or stationary. Construction waste generated by construction activities are of two types: (1) inert, (2) non inert. The non inert waste comprises of bamboo, timber, vegetation, etc. The inert waste comprises of construction debris, rubble, aggregate, etc. The inert material can be crushed and screened on-site their by reusing aggregate, gravel, concrete etc. The crushing plant comprises of jaw crusher, belt conveyor as well as screening machines.

4.1.16 Baling

Balers are used for baling corrugated cardboard, paper, aluminum cans, plastic containers etc. Balers are available in a wide range of sophistication. Bales of waste are tied with wire/string of durable material like iron or nylon. Some high-power balers form bales which will retain its shape without strings/wires.

4.1.17 Ballistic Separators

Ballistic Separators are used for segregating large materials such as plastic bottles, metal cans from waste stream. The separator consists of a series of oscillating paddles in pairs wherein large objects move backwards and light fractions move forward. The angle is set as per material separation requirements.

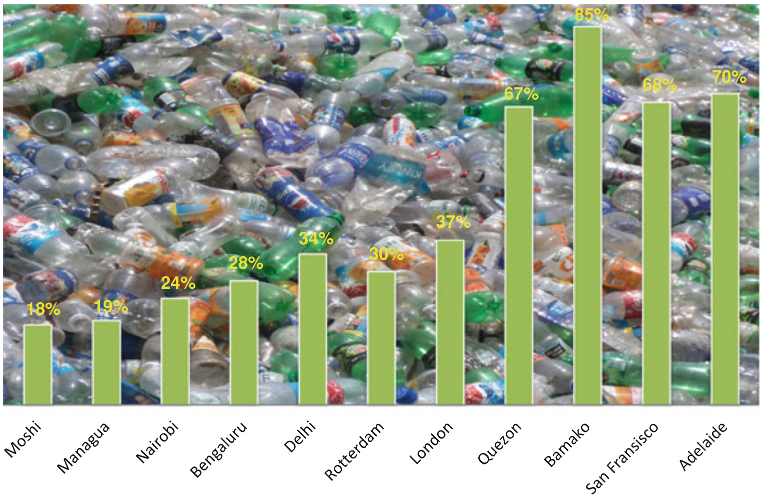

Fig. 4.27 Recycling in percentage at various cities across the world

4.2 Reuse and Recycle

Reuse and recycle is the oldest waste management practice that the mankind has adopted in the civilisation. For example, man used bones as tools. In India even today charcoal and crushed brick is used for cleaning teeth by many poor people. During the past 10–20 years, the developed countries are rediscovering the worth of recycling as part of their waste management systems and these countries have invested in physical infrastructure and communication strategies to amplify recycling rates (UN-habitat 2010). The newspaper is used for packaging and old bottles are recycled for refilling beverages. Used cloths which are waste for affluent people are used by poor all over the world. The USA, Germany, France and the Netherlands use bottom ash from waste incinerators for road construction (Mullen 1990; Chandler et al. 1997).

Industrial waste like coal combustion residues, steel slag, and red mud (of bauxite) can be used in concrete, bricks, blocks, and tiles. Similarly gypsum produced as waste from industry can be used for manufacture of gypsum board and cement.

After the extraction of oil from oil palm fruit, husks and shells are used in captive power plants. Similar use can be seen in sugar mills wherein bagasse (leftovers after extraction of juice from sugar cane) is used as fuel for cogeneration. Coconut fibres can be used for making rope or fibre-cement board. The finely ground glass with a particle size finer than 38 μm and can be used as a substitute for Portland cement in concrete (Safiuddin et al. 2010). The construction and demolition waste can be used for embankments, pavement and concrete.

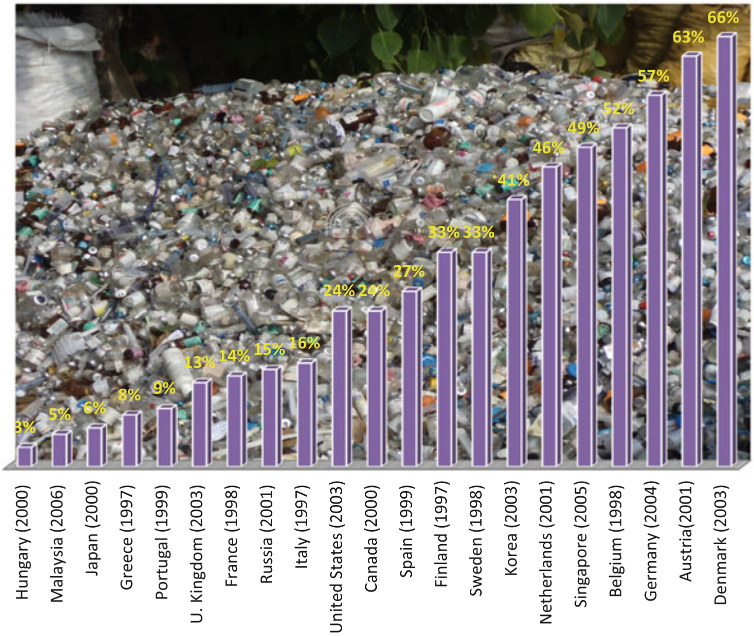

Fig. 4.28 Recycling in percentage at various countries

Recycling/reuse which is also referred as valorisation in some literature has been practiced throughout the world. As per UN-habitat (2010) the recycling is carried out in various cities as shown pictorially in Fig. 4.27. Data collected and published by Saleh (2011) depicting recycling achieved in various countries is given in Fig. 4.28. Many developing and transitional nations have active informal sector which is engaged in reuse and recycling. Not only does such arrangement provide livelihoods to vast numbers of the poor people, but they save the city nearly 15–20 % of its waste management expenditure (UN-habitat 2010).

The European Union (EU) is in forefront with respect to the efforts across the Europe to minimize waste by issuing numerous specific directives and therefore there is rise in recycling from 11 % between 1985 and 1990–29 % in 2000 (Saleh 2011; Slater and Frederickson 2001). In USA more than 71 % of corrugated boxes, 82 % newspapers, 56 % office papers, 44 % aluminum beverage cans (Hristovski et al. 2007) are recycled. 31 % of MSW being composted representing 23 % of all material recovered (Saleh 2011). MSW recycling increased from 15.6 % in 2002–2003 to 19.0 % in 2003–2004 in the UK (Saleh 2011). There are more than 160 community recycling sites in the UK (Garg et al. 2009). Nearly 66 % of the total waste was recycled in Denmark during 2003 and about 57 % of waste was recycled during 2004 in Germany (Saleh 2011). The recycling increased from 50 to 77 % between 1985 and 2000 in Netherlands (Saleh 2011).

Fig. 4.29 An example of reusing. Bins used for chemicals are being used for growing plants

Fig. 4.30 Storage yard before recycling

Large quantity of waste materials discarded during petroleum exploration industry. As per studies conducted by (Souza et al. 2011) solid petroleum waste (SPW) can replace natural clay material up to 30 wt %. Studies conducted by Paola (2011) revealed that fennel and lemon wastes can provide substantial enzyme production yields whereas carrot waste supported Poly-Hydroxybutyric Acid production.

Table 4.2 shows example of using of some of the components of waste. Figure 4.29 shows an example of reusing wherein bins used for chemicals have been used for growing plants. Figure 4.30 shows a storage yard before recycling. Figure 4.31 shows chemical bins, printed flex sheets used for advertisement kept for sale. Agro-waste like baggage, rice straw, wheat straw, and rice husk, saw mill waste, ground nut shell, jute, cotton stalk, vegetable residues can be used for manufacture of particle boards, insulation boards, wall panels, roof sheets, fibrous building panels and bricks.

Fig. 4.31 Chemical bins, printed flex sheets used for advertisement kept for sale

Recycling was never a new approach in developing countries as one man's waste is resource for other person. Considering poverty in developing countries nothing will be wasted as long as it can earn or save some money. But during 1980s recycling of waste was favored against disposal in developed countries. In 2009, recycling which included about 9,000 curbside recycling and around 3,000 yard trimmings composting programs recovered 33.8 % of MSW generation in 2009 (USEPA 2010).

Figure 4.32 shows waste processing at a typical material recycling facility in developing country which is more machine dependent. The methods for recovering recyclable from MSW are: (1) source separation, (2) separation of comingled waste at MRFs, (3) Separation at MRF preceded by front end processing facilities.

4.2.1 Aerobic and Anaerobic Treatment

Aerobic treatment is a process wherein waste is degraded by bacteria in the presence of oxygen. In the case of anaerobic treatment degradation is carried out in

Table 4.2 Examples uses of some of the components of waste

Waste	Use
Coconut shell	Activated carbon, fuel
Egg shell	Plant feed, source of calcium
Used printed flex sheet used in hording	Blanket, mat, tarpaulin to cover agricultural product, water proofing in roofs
Used chemical drums	Growing plants, container for water in houses
Glass pieces	To place it on compound walls for added security
Food waste	Composting, animal feed
Newspaper	Packaging
Dried skin of citrus fruits	Fragrance agents in floor/toilet cleaners

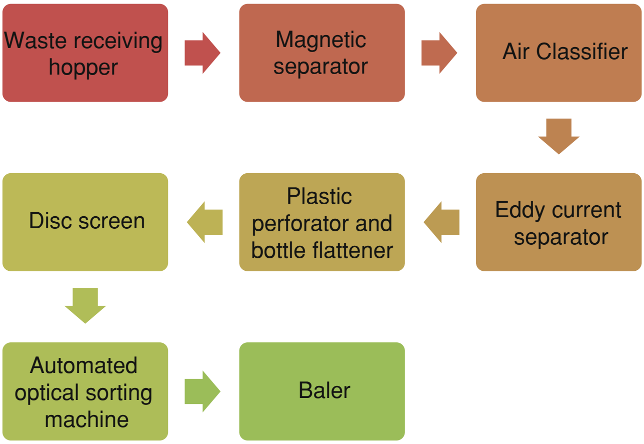

Fig. 4.32 Waste processing at a typical material recycling facility

the absence of oxygen. The subsequent paragraphs discuss some of the widely used aerobic and anaerobic treatment methodologies.

4.2.2 Composting

Composting is a method of reusing known since times immemorial. Waste composting is a technology for treating organic fraction. But all the facilities are not operated smoothly. Of the 19 facilities contacted by Renkow (1998), one facility was stopped due to cost problems and liability, one was forced to close because of odour problems, and one was shut down due to technical problems. The cost of the mechanical turner and shelters are the major investment needed.

Composting of solid waste involves three steps namely, (1) preparation, (2) decomposition, and (3) product preparation.

Waste segregation		Waste segregation is done to separate biodegradable fraction of waste. Shredded to reduce size of waste component for proper handling and increase surface area so that microbes can decompose at a faster rate.
Composting in windrows	  	Windrows of organic material are formed either in dedicated shelter or in open atmosphere. Humidity is maintained by spraying water; temperature is maintained by proper mixing and passing heat through heaps; pH is maintained by adding lime or other basic material. Commercially available microorganism or old compost is added to inoculate microorganism.
Screening		Screening is carried out to separate larger non degraded fraction.
Packaging		The final fine particles of compost are packed and marketed.

Fig. 4.33 Large scale composting

Composting is the decay of organic material by microorganism in artificially controlled facility. The composting is suitable for biodegradable fraction of a waste stream. The method is not suitable for wastes that are too wet during which dry waste may have to be added or the leachate in the waste be drained. Issues of methane emission, flies and odour from poorly managed compost plants may need to be tackled. Improper waste segregation there will lead to entry of toxic substance into the stream of MSW affecting activity of micro-organism.

The two composting processes used are windrow-based composting and in-vessel composting. In the window system, waste is formed into windrows that are 1–2 m high (Fig. 4.33). These windrows are turned time to time by means of an automatic turning machine or manually. In order to maintain a constant temperature. Water is added to maintain optimum moisture content. After a required level of decomposition is attained, the composted material will be ready for use in agricultural application. Windrows can also be aerated by passing air through pipes into the windrows. An idealised version of windrow compost is one that could be housed in a shelter. The shelter would be provided with the ventilation equipment or kept open depending on climatic conditions of the areas. The innovation and cost saving have led to the use of plastic sheets to cover the windrows to protect the windrows from rain and other elements of weather. Plastic litter and other disintegrated materials in the compost product can be removed by screening.

The in-vessel or compost tanks are constructed with provision for drainage and aeration (Fig. 4.34). In in-vessel systems decay of organic materials is carried out in large sophisticated vessels built for speeding biological decay by controlling oxygen, temperature, moisture content and carbon to nitrogen ratios. Usually

Fig. 4.34 Composting tanks

coarse material of 40 mm makes the bottom layer, over which pebbles of smaller dimensions and gravels are placed to avoid water logging, easy for drainage. While it is essential to maintain pH, humidity and temperature at optimum level, field conditions may not allow this. But as a precautionary principle citrus fruits and other acidic substances may be segregated to avoid drop in pH. Occasional spraying of water to maintain humidity is essential. Proper ventilation ensures optimum temperature by avoiding heat build-up due to bacterial activity within the tank (Fig. 4.34).

Factors affecting composting are shown in Table 4.3. The time required for composting varies from one to 3 months. Addition of nitrogen source like urea may be required to optimise the process. Increase in temperature would increase the rate of biological activity. But the rate of activity of enzymes and microorganism would decrease if the increase in temperature rise is more than the optimum temperature required for species responsible for composting. The activity of cellulose enzyme will reduce at temperature more than 70 °C. Optimum temperature for nitrification is 30–50 °C beyond which nitrogen loss will occur.

Vermicomposting is a process of composting in which earthworms are used for conversion of waste into compost (Fig. 4.35) The vermicomposting is carried out at 10–32 °C (temperature in the pile of waste). The process is quicker than composting as the material passes through the gut of earthworm. Vermicompost is superior to conventionally produced compost. Worms can be used as a high-quality animal feed.

Disadvantage of vermicompost is that it requires more labour and space as worms do not operate in waste heap more than a meter in depth. The worms are vulnerable change in temperature, pH, toxic substance and other inhibiting factors like water logging. Vermicompost requires more worms and, hence, worms need to be procured prior to starting vermicompost plant.

Vermicomposting needs bedding with high absorbency, good bulking potential and high carbon to nitrogen ratio. Worms respire through their skins and hence

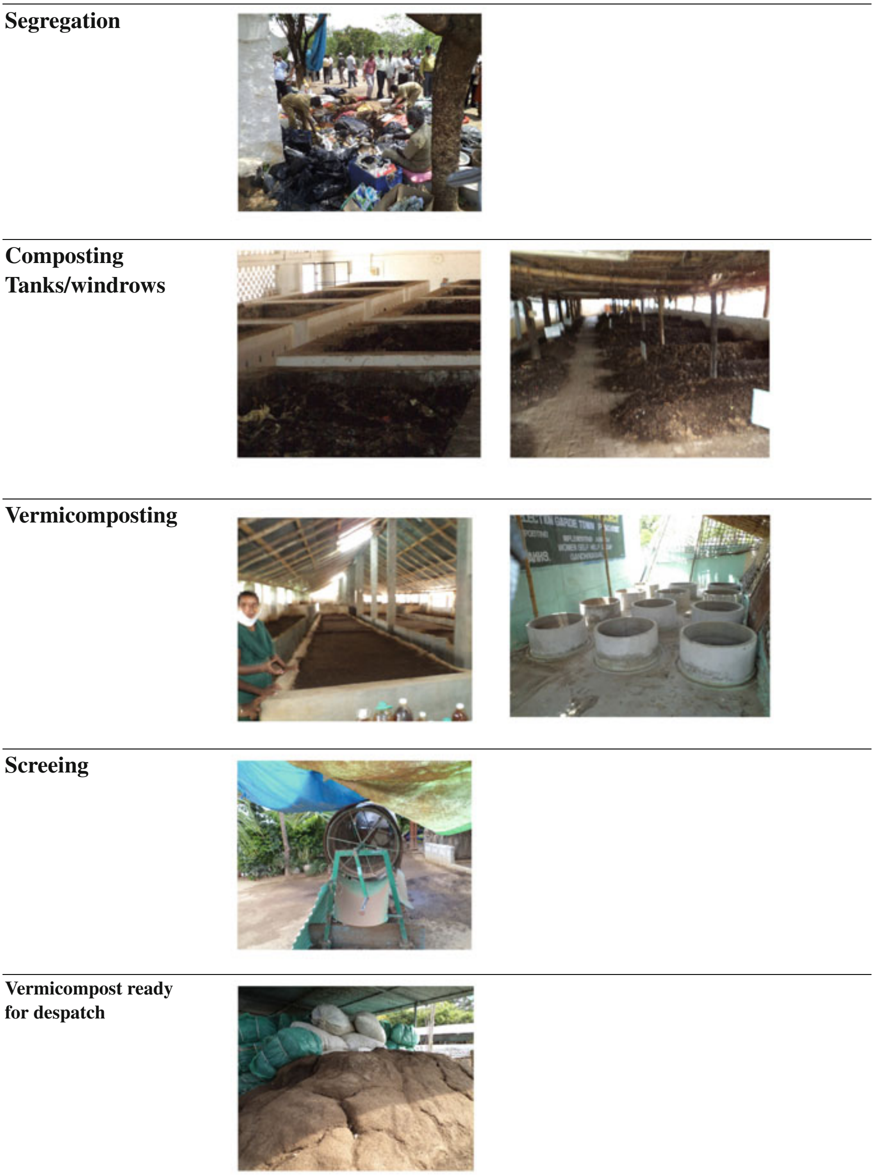

Fig. 4.35 Vermicomposting process

must have a moist environment. The bedding must be capable of absorbing and retaining water. Flow of air is reduced or eliminated if the material is packed too tightly leading to reduced oxygen in bedding. Rapid degradation and associated heating is not favourable to worms and could be fatal. Some of the materials that

Table 4.3 Important factors affecting composting of waste

Factors	Comment
Waste size	For optimum results it is necessary that size be in the range of 45–75 mm
Seeding	Seeding like animal dung, sewage sludge, compost or commercially available microbes will enhance speed of decomposing. The seeding required would vary from 1 to 5 % by weight
Mixing/turning	Required to avoid drying, caking, air channeling. The requirement of mixing and turning depends on waste type
Moisture content	Moisture content of 50–60 % would give the optimum results
Temperature	For best result the temperature required is between 50 and 60 °C depending on type of waste. Beyond 66° the activity of bacteria would be reduced to great extent
Carbon to nitrogen ratio	Carbon to nitrogen ratio between 50 and 60 would be optimum
pH	It is desirable to maintain a pH between 6 and 8

can be used for beds are coconut fibre, hay, straw, paper, bark, corrugated card board, saw dust, wood chips, dry leaves, corn stalks and corn cobs.

Earthworms consume organic matter and reduce the volume by 40–60 %. The earthworms consume the biodegradable matter and generate excreta referred as vermi-castings. Each earthworm weighs approximately 0.5–0.6 g, eats organic matter equal to its body weight and generates cast equivalent to around 50 % of the organic matter it consumes in a day.

Vermicomposting provides the growth enhancing hormones and nutrients and, are required for plant growth. Plant products grown with vermicompost have been reported to be of good quality.

Normally the beds are 75–90 cm thick with provision of filter for draining excess water. The bed should be with uniform height through out the length and width. The bed width should be sufficient to allow easy access to the centre of the bed and, hence, 1.5 m wide is recommended and practiced. Length and width of bed do not matter as long as the temperature of 20–30° and moisture content of 40–50 % are maintained. The number of earthworms introduced varies between 300 and 400 worms per m^3 of bed volume for optimum result.

Eisenia fetida, Eudrilus eugeniae, Perionyx excavatius are some of the best species for used for vermicompost. The life of earth worms is about two years. One earthworm would reach reproductive stage in about 6 weeks and worms at the reproductive stage will lay egg capsule every 7–10 days and three to seven worms will come out of each capsule. Hence the multiplication of worms in optimum environment is very fast. Fully grown worms can be separated and dried to make 'worm meal' for use in animal feed as it comprises of 70 % of protein (Keralaagriculture 2011).

The worms should be fed with waste that provides nutrition to worms waste should not contain material that generates heat due to decomposition. The waste should also be devoid of excess moisture, grease, salt and chemical that is detrimental to worms. Extreme pH would also affect worms and hence the waste should

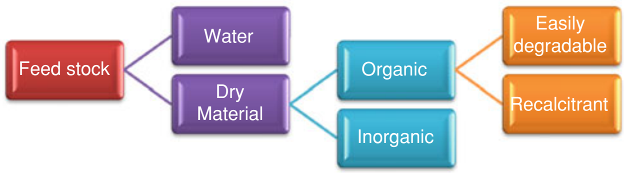

Fig. 4.36 Components of feedstock

be devoid of citrus fruits and other acidic substances. Hence it is advisable to pre-compost partially prior to introduction of worms. For optimization of the vermi-compost it would be necessary to have batches of one month after which the compost need to sieved and larger fractions be returned to vermicompost pit. Worms are food for birds, moles, ants, centipede, ants and mites. Hence it is essential that worms are protected by covering or constructing beds in sheds. In spite of the above constraints vermin compost is carried out massively as the vermicompost stimulates the plant growth (Atiyeh et al. 2000) and provide resistance to plant deceases (Glenn 2012).

4.2.2.1 Anaerobic Digestion

Anaerobic Digestion (AD) system was used by the Assyrians in the 10th century BC and in Persia during the 16th century (Christian and Dübendorf 2007). Most of the AD system was done in anaerobic ponds prior to 1920. The industrialization of AD system started in 1859 by the first AD system in Bombay (Now Mumbai), India. The energy crisis in 1973 and 1979 triggered development of AD systems for methane production. Industrial countries are now using the technology for treatment of municipal as well as industrial waste.

Volatile fatty acids (VFA) generated by hydrolysis-acidification should properly be balanced in AD system as methanogenic bacteria are sensitive to presence of VFA. Production of VFA higher than the methanogenic rate will lead to failure of the AD system due to accumulation of VFA.

Figure 4.36 shows the components of feed stock. The organic matter can be divided easily degradable (like proteins, fats and carbohydrates) or can be recalcitrant (like lignin and cellulose). Fats are decomposed to glyceride and organic acids hence the presence of too much fat in the feedstock will lead to accumulation of organic acids resulting in decrease of pH and inhibition of degradation. Carbohydrates are degraded into mono-saccharides or acidic acids. Feedstock rich in starch/saccharide will be quickly converted into acids leading to drop in pH and digester will turned into irreversible state of acidification. Proteins consist of nitrogen, sulfur and phosphorus resulting in generation of ammonium and hydrogen sulfide.

Each bacteria culture has its own optimum temperature range and hence a temperature fluctuation should be avoided. Variability in feedstock will affect the performance and as such variation does not allow microbes to get acclimatised.

4.2.3 Road Making

The use of waste materials in asphalt pavement represents an optimistic outlet for such materials. Use of such material comes with property needs and technical restriction. Such needs and restrictions lead to processing cost which is higher than cost of virgin aggregates. Glass, steel slag, scrap tyre and plastic can be used for road making (Yue et al. 2007). While scrap tyre and plastic can be used as binder all the four material mentioned can be used as aggregate.

Use of 10–15 % crushed glass with 4.75 mm maximum size in surface course has shown satisfactory performance in asphalt pavements (Yue et al. 2007). The same equipment and method designed for conventional asphalt can be used for asphalt with recycled glass (Airey et al. 2004; CWC 1996; FHWA 1997; Maupin 1998; Su and Chen 2002). Anti-strip agent, usually 2 % hydrated lime, is added to maintain the stripping resistance. Glass in asphalt of higher content and larger size is likely to result in inadequate friction and bonding strength(Yue et al. 2007).

The angular shape, hardness and rough surface makes steel slag substitute coarse aggregates in asphalt. Scrap tyre can be used by dissolving crumb rubber in the bitumen as binder modifier. Portion of fine aggregates can be replaced with ground rubber. Plastics can be used either as aggregate by replacing a part of aggregates, or as a binder modifier.

4.2.4 Removal and Recovery Method

In this method waste is blended with solvent and subject to distillation treatment for recovering organic fraction which has combustible value. Organic acids formed during anaerobic digestion was recovered using freezing and thawing, centrifugation, filtration as well as evaporation (Farah et al. 2009).

4.2.5 Stabilization

In this method waste is mixed with solidification agent such as cement/asphalt before land disposal. The procedure is adopted elaborately for hazardous waste fraction in order to safeguard environment from possible leachate generation and reaction with in compatible substances. A more details discussion on the topic is done in Chap. 7.

4.2.6 Deactivation

This treatment is primarily used for corrosive wastes and explosives. In this method corrosive and explosive wastes are blended with suitable chemicals prior to disposal in land fill to avoid possible reaction in the landfill.

4.2.7 Metal Removal and Recovery

This method involves precipitation of heavy metals from semisolid waste like sledges followed by recovery of metal from precipitate. Metal ions form complexes with water-soluble polyelectrolytes, which can be precipitated with polybases for recovery of metals (Jellinek and Ming 2003). Hydroxide and Carbonate precipitation could be used for recovery of manganese (Wensheng et al. 2010).

4.2.8 Aqueous Treatment

This treatment includes biological treatment, wet air oxidation, chemical oxidation/reduction. In this method waste is subject to treatment after mixing with water. Biological treatment can be aerobic or anaerobic which is already discussed in Sect. 4.2.1.

4.2.9 Plastic Granulating

Some materials (e.g., plastic bottles) can be shredded by slow-speed shears to reduce size of plastic objects. The process is called plastic granulating.

4.2.10 Emerging Biological Technologies

Out of many emerging technologies bio-drying, aerated static pile composting, mechanical waste biological waste treatment, and aerated static pile composting are commonly used.

In bio-drying biodegradable waste is rapidly heated in the initial stages of composting to remove moisture (Choi et al. 2001; Navaee-Ardeh et al. 2006; Sugni et al. 2005; Velis et al. 2009). In the mechanical waste biological waste treatment, waste is sorted out in the first step followed by mixing, moistening and biological degradation (GTZ 2003). In aerated static pile composting, perforated channelled concrete floor with piping is used for supplying oxygen to the degradable fraction of solid waste.

Feeding of MSW to larvae constitutes a benefit for low income countries. Black soldier fly, Hermetia illucens, has been studied and found that waste can be reduced from 65.5 to 78.9 % and prepupae can be used as additive in animal feed (Stefan et al. 2011).

Biologically produced hydrogen (or bio-hydrogen) can be produced by wide variety of microorganisms under anoxic conditions (Gustavo 2008).

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Chapter 5
Disposal

The main disposal methods for municipal solid waste (MSW) is open dumping and sanitary landfill. Uncontrolled dump sites are smoky with a lot of leachate generation with severe environmental pollution. On open dumping grounds generate foul odors and habitat for vectors and rodents. The disposal need not have to occur within the same country. For example, some materials from waste in Bahrain are exported after being compressed to a scale below their actual size.

Since the landfill is restricted by European Commission and its member countries, waste derived fuel from MSW is strategic component of integrated waste management policy. In Denmark and the Netherlands, land filling of MSW is already in place. However, some bulky waste is land filled in Denmark and the Netherlands. Separated combustible waste cannot be land filled in Sweden since 2002 and the land filling in France is limited to an 'ultimate waste' since 2002 (EC 2003).

5.1 Landfill

Historically countries disposed waste on land and covering it up. In many cases uncontrolled burning of waste would precede or follow dumping activity. Landfills are the final depository of a waste after all other waste management options have been carried out. Landfills can be categorized according to open dumps, controlled dumps or sanitary landfills (or secured landfill or engineered landfill). Figure 5.1 shows a typical schematic diagram of landfill.

An engineered landfill or sanitary landfill facility is an integrated waste management disposal system. Disposal in an engineered waste landfill facility is the final stage in the waste management process, providing long-term confinement of waste materials. An appropriate treatment may be needed to process the waste for final disposal. Some of the processing may include minimizing or eliminating hazardous properties, stabilizing the waste, and/or reducing its volume. Engineered

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bioreactor landfills are designed to minimize the infiltration of rainwater and/or snowmelt into the solid waste. Over the past decade or so, several field scale pilot studies have been conducted to develop and improve landfill techniques and designs.

Sanitary landfill facilities are generally located in areas where the potential for degradation of the quality of air, land, and water is minimal. Similarly, a sanitary landfill should be located away from an airport to avoid air accidents between birds and aeroplanes. The location should preferably be outside 100-year flood plain and should not be located in the close proximity of wild life sanctuaries, monuments and other important places which is ecologically important. Location of sanitary land fill should also consider seismic sensitivity of the area to avoid environmental damage during earthquake. Table 5.1 shows important factors to be considered while evaluating a landfill site.

In comparisons to other possibilities, landfill should be the last option to manage waste. For example, Denmark which generates about 13 million tons of waste per year has banned land filling waste suitable for incineration (DEPA 1999).

Landfill is the physical facility specifically designed, constructed and operated for the disposal of waste. Even after well-planned waste reduction, recycling and transformation programs, the residual waste from such operations still ends up on a landfill.

Landfills can also be classified into general or hazardous waste disposal site based on the waste disposed.

A typical landfill will undergo the following activities during its life time: (1) planning, (2) site selection, (3) site preparation, (4) landfill bed construction, (5) leachate and gas collection system incorporation, (6) land filling, (7) monitoring, (8) closure of landfill, and (9) post closure monitoring.

This section discusses the general landfill objectives and practices. The special precautions and practices followed in hazardous waste land fill are discussed in detail in Chap. 7.

The typical landfill process during operation involves: (1) waste dumping at the working face, (2) waste spreading, shredding and compaction, and (3) waste covering (Fig. 5.2).

The land fill method can be broadly classified into trench method, area method and depression method as explained in the subsequent paragraphs.

Excavated Cell/Trench Method: This method is ideally suited in areas where there is an adequate depth of cover material and water table is not near the surface. In this method, solid wastes are placed in cells/trenches excavated in the soil (Fig. 5.2). The soil excavated in the site is used for daily/final cover. The cells/ trenches are lined with lining system to restrict the movement of landfill gases and leachate. The cells are provided with side slopes of 2:1–3:1 and vary from 50 to 300 m in length, 1–3 m in depth, and 5–15 m in width.

Area Method: This method is used where the terrain is not suitable for the excavation of cells or trenches. Liner system as provided to manage leachate and cover material must be hauled from other places.

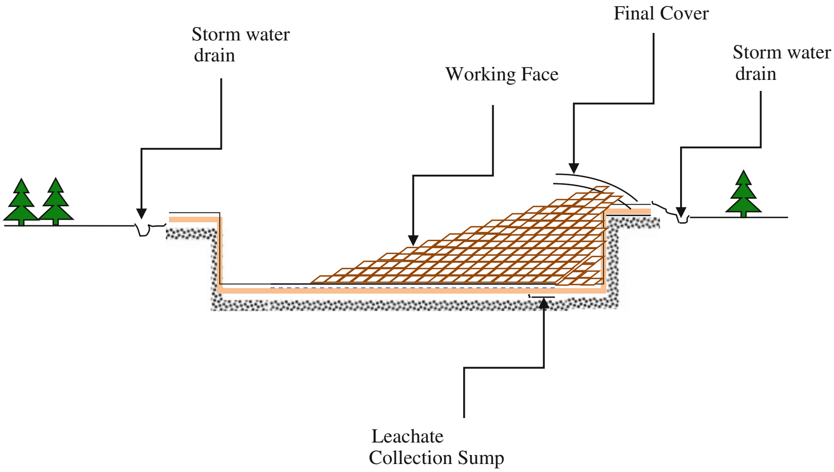

Fig. 5.1 A typical schematic diagram of landfill

Table 5.1 Important factors to be considered while evaluating a landfill site

Sl. No.	Factor	Remark
1.	Access to land	Existing road/railway/water way should be considered
2.	Climate	Rainfall, temperature, humidity, wind speed, snow fall etc., need to be considered
3.	Disaster history of the location	Earth quake, cyclone, draught, flood, tsunami, hurricane, terrorism, war, sabotage, industrial accidents etc. shall be evaluated
4.	Extent of land available	Should be capable of accepting waste to an extent so that an investment is feasible
5.	Final use of land	Long term use of land needs to be evaluated
6.	Geology and hydrogeology	Groundwater quality and quantity as well as permeability of the geological strata need to be studied
7.	Haul distance	Distance from source/transfer station decides to economy of operation especially when a site receives waste from more than one source
8.	Local and national legislation	Regulatory issues decide the ultimate location
9.	Local environment	The local environment with respect to biota, monuments, religious setting, physico-chemical environment like noise, air quality, water quality, land use pattern shall be considered
10.	Public acceptability	Local public shall accept the idea and project for success of the project
11.	Soil sharacteristics	Soil characteristics and availability of cover material need to be evaluated
12.	Surface water hydrology	Drainage pattern, distance from major water bodies, water shed boundaries shall be considered
13.	Topography	Contours and slope need to be studied

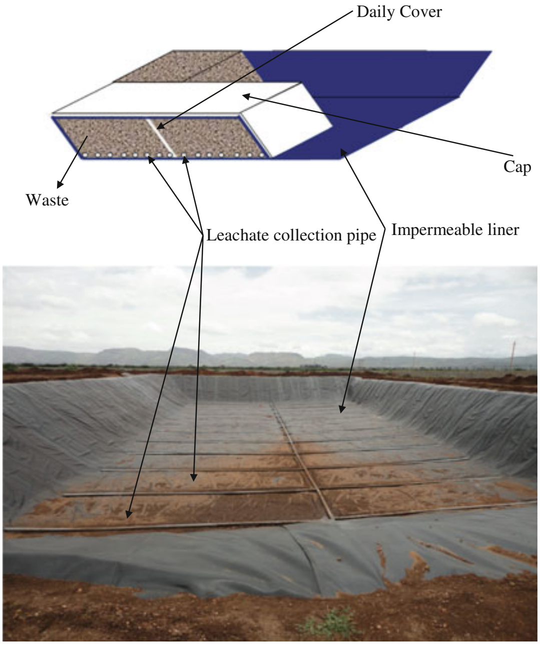

Fig. 5.2 Typical trench method of landfill setup

Canyon/Depression Method: In this method compact solid waste is placed in canyon/depression. Usually, filling begins at the head end of the canyon and concludes at the mouth, in order to prevent the gathering of water behind the landfill. In this method sites are filled in multiple lifts.

Landfill Airspace which is the permitted height, length and breadth the landfill may finally occupy. Landfill airspace determines the lifespan of a site. Efficient operations will increase the use of the space. Once airspace is completely utilized the site is closed and capped with a layer of impermeable clay and layer of top soil. Grass and other suitable vegetation types are planted on landfill site to stabilize the soil and improve the appearance. Environmental monitoring is carried out for a period of up to 30 years after the closure of the site. Table 5.2 shows examples of landfill sealants. Table 5.3 shows factors to be considered landfill design. Table 5.4 shows factors to be considered during construction and operation. Table 5.5 shows factors to be considered during post closure.

5.1.1 Processes Within a Landfill

Organic matter in MSW composes of mainly of proteins, lipids, carbohydrates, and lignins which are easily degradable. Other organic matter like lignin and cellulose are recalcitrant. Some of the biodegradable portions are readily biodegradable and others are moderately biodegradable fraction. The landfill ecosystem is diverse and hence promotes stability, however, it is influenced by environmental conditions like temperature, pH, moisture content, etc.

Stabilization of MSW in landfill happens in five phases (Willium and Aarne 2002). Such phases may not happen at all in landfill meant exclusively for C&D hazardous waste. The five phases occurring in MSW landfill sites are:

(1) **Initial Adjustment Phase**: In this phase microbes acclimatize to the landfill condition.
(2) **Transition Phase**: In this phase transformation from aerobic to anaerobic environment occurs.
(3) **Acid Formation Phase**: The continuous hydrolysis of solid waste, followed by the microbial action on biodegradable organic fraction results in the generation of intermediate volatile organic acids.
(4) **Fermentation Phase**: During this phase, intermediate acids are converted into methane, carbon dioxide, hydrogen sulfides and ammonia, by microbial action.
(5) **Maturation Phase**: During this phase nutrients become scare and the biological activity shifts to dormancy resultin in drop in gas production and and leachate strength will be at lower concentrations. Slow decomposition of resistant organic matter may continue resulting in humic-like substances.

5.1.2 Controlling Leachate and Gas

Wastes in land fill generate leachate which is defined as the water that has percolated through the wastes which is a source of soil and groundwater pollution and gas produced by the fermentation of organic matter. Precipitation is the major reason for generation of leachate. The soluble and suspended components from the biodegrading waste will combine with percolating water in landfill site through series of complicated physical and chemical reactions. Other contributors to leachate creation are groundwater inflow, surface water runoff and biological degradation (Reinhart and Townsend 1998).

The quantity of leachates depends on: (1) rainwater percolation through wastes, (2) biochemical processes in waste's cells, (3) inherent water content of the wastes, and (4) the degree of compaction of the waste. The leachate production is usually greater when the waste is less compacted as compaction reduces the filtration rate (Lema et al. 1988). Composition of leachates from landfill varies with the age of the landfill (Silva et al. 2004). As landfill age increases, concentration of organics in the leachate decreases whereas the concentration of ammonia nitrogen increases (Kulikowska and Klimiuk 2008; Cheung et al. 1997). Recirculation of leachate may result in high concentrations of ammonia but lower concentrations of degradable carbon compounds (Cheung et al. 1997).

Leachate disposal into the sewer system has advantage of easy maintenance and low operating costs (Ahn et al. 2002). Recycling leachate back into landfill is one of the least expensive options for treating leachate (Lema et al. 1988). Lagooning

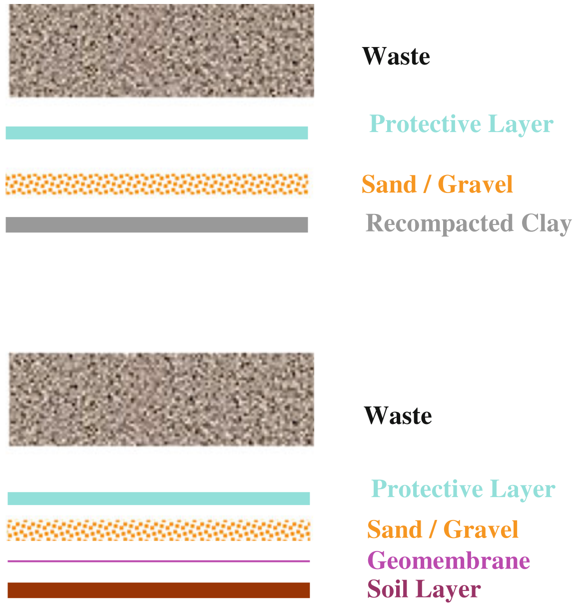

Fig. 5.3 Examples of single liner system

may not be a acceptable treatment option for leachate (Zaloum and Abbott 1997). Activated sludge processes found to be not adequate for treating landfill leachate treatment in recent decades (Lin et al. 2000). Flotation has been used for many years to decrease colloids, macromolecules, ions, microorganisms and fibres (Zouboulis et al. 2003).

Coagulation-flocculation can be utilised in treating stabilized leachates from old landfill sites (Silva et al. 2004). Chemical precipitation can be used as leachate pre-treatment to eliminate high strength of ammonium nitrogen (Abdulhussain et al. 2009). Chemical oxidation is necessary for the treating of wastewater with soluble non-biodegradable organic/toxic substance (Marco et al. 1997). Ammonium stripping is widely used for the removal of ammonia nitrogen from landfill leachate (Abdulhussain et al. 2009). Electrodialysis, microfiltration, nanofiltration, ultrafiltration and reverse osmosis are used if high quality treated effluents are required.

Single-Liner Systems

Single liners (Fig. 5.3) contain clay liner, geosynthetic clay liner or geomembrane. Single liners are used in landfills designed for construction and demolition of debris.

Composite-Liner Systems

A composite liner (Fig. 5.4) comprises of geomembrane and clay liner. Composite-liner systems are more efficient at limiting leachate migration. Composite liners are used mostly in MSW landfills.

Double-Liner Systems

Double-liner systems (Fig. 5.5) are used widely in hazardous waste landfills. A double liner contains either two composite liners or two single liners or

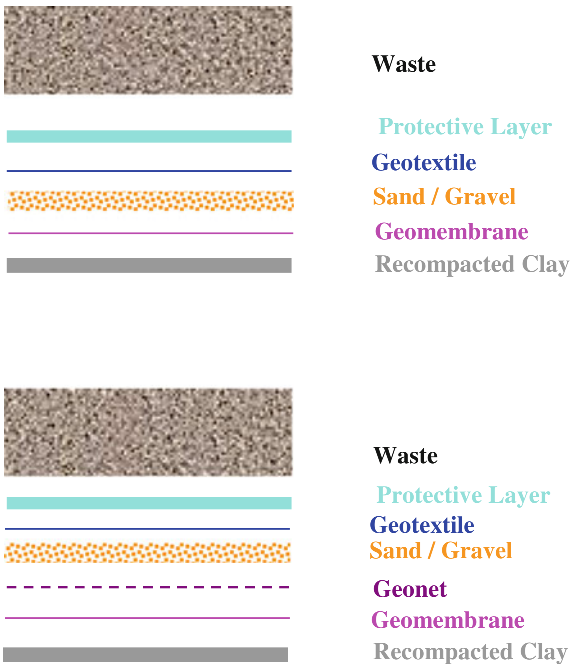

Fig. 5.4 Examples of composite liner systems

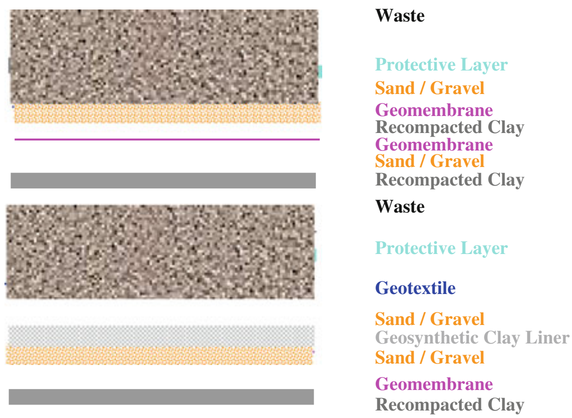

Fig. 5.5 Examples of double liner system

combination of a single and a composite liner. The upper liner functions to collect the leachate whereas the lower liner backup to the primary liner and used for leak detection.

Leachate Collection Systems

All liner systems are integrated with leachate collection system. Leachate collection system is composed of gravel and sand or a geonet (plastic net-like drainage blanket) along with a sequence of leachate collection conduits to drain the leachate to holding tanks for treatment (Fig. 5.6).

Fig. 5.6 Leachate treatment facility

The upper drainage layer of double-liner systems acts as a leachate collection system and the lower drainage layer is used for the leak detection. The leachate in the lower drainage alerts landfill management to take necessary corrective action.

Components of the liner system are provided with protective layer composed of soil, sand, and gravel or a layer of soft solid waste such as paper, shredded tires, organic refuse, and rubber.

Liner Components

Clay: Clay liners are laid to avoid groundwater contamination. A simple liner will comprise of 30 cm–1 m thick compacted clay layer. The effectiveness of clay liners is affected by fractures stimulated by freeze–thaw cycles, presence of some chemicals and drying out.

Geomembranes: Geomembranes or flexible membrane liners (FML) are constructed from a variety of plastic materials which include polyvinyl chloride (PVC) as well as high-density polyethylene (HDPE). Figure 5.2 shows geomembrane layed before placing waste in landfill and Fig. 5.7 shows geomembrane placed on landfilled waste prior to closure and Fig. 5.8 shows position of geomembrane in landfill cap.

Geotextiles: Geotextiles (Fig. 5.9) allow the movement of water and trap particles to reduce blockage in the leachate collection system. They are used to avoid the movement of minute waste and soil particles into the leachate collection system and to protect geomembranes from punctures.

Geosynthetic Clay Liner (GCL): These liners comprises of a clay layer of 4–6 mm between the layers of a geotextile.

Geonet: A geonet is net-like drainage blanket of plastic used in landfill liners in place of gravel or sand for the leachate collection layer. Geonets are more vulnerable to clogging by minute particles.

Storage of solid waste in landfills contributes to the greenhouse gas (GHG) due to degradation of organic component of waste. Total European emissions are about 2 % of the total GHG of 5,000 Million ton per year (EEA 2009). Areal emission

Fig. 5.7 Geomembrane placed on landfill prior to closure

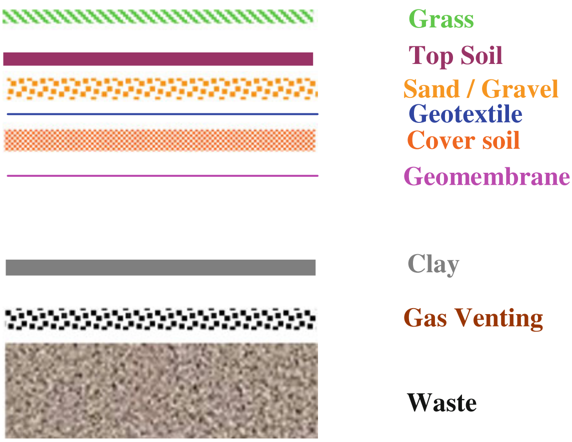

Fig. 5.8 Example of different layers in landfill cap

Fig. 5.9 Geotextile in Land fill area

Table 5.2 Examples of landfill sealants

Sl. No.	Sealant	Example	Remarks
1.	Compacted soil	Silt, black cotton soil, sand	Should contain cohesive property
2.	Compacted clay	Bentonite, Kaolinites	Layer must be continuous and should not be allowed to crack
3.	Inorganic chemicals	Sodium silicate, pyrophospate	Use must be decided based on availability and local soil characteristics
4.	Synthetic chemicals	Polymers	May be considered after pilot studies
5.	Synthetic membranes/ Geotextile	Polyvinyl chloride, polyethelene	Properties of material and available skills within operating staff need to be considered
6.	Asphalt		Layer must be continuous and should not be allowed to crack
7.	Others	Concrete, tiles	May be considered suitable after pilot studies

Table 5.3 Factors to be considered in landfill design

Factors	Remarks
Access	Road, rail and other transport mode
Cell construction and Cover material	Cover material available onsite and off site
Drainage	Existing and required drainage
Emergency Preparedness Plan (EPP) and Disaster Management Plan (DMP)	Comprehensive EPP and DMP should prepared
Environment Management Plan (EMP)	Extensive EMP should be prepared
Equipment requirement	Need to be assessed
Extent of land area	To be arrived considering on at least 10 years of operation
Land filling method	To be evolved depending on local environmental setting
Litter/rodent control	Litter/rodent control plan should be finalised
Onsite storage and pretreatment	May be required in case hazardous and special waste
Project specific consideration	Need to considered considering local requirement like loss of livelihood, market for salvaged material
Regulatory issues	Need to be considered extensively
Reception, weighing, security, Unloading and vehicle washing etc.	Provision shall be made for reception, weighing and security
Spread and compaction	Need to be considered type of waste and cover material

rate of gaseous pollutants from landfills is difficult to control and meteorological factors some time lead to enhancement of lateral migration of Land Fill Gas (LFG) that cause gas explosion accident (Mohammed et al. 2009) Tables 5.2, 5.3, 5.4 and 5.5.

Table 5.4 Factors to be considered during construction and operation of landfill

Factors	Remarks
Communication	Shall have comprehensive communication arrangement
Days and hours of operation	Should consider non-operating period due to holidays/calamities/climatic reason
Employee facility	Shall have proper rest house and bath room
Environment monitoring and surveillance	Shall have comprehensive environment monitoring and surveillance arrangement
Equipment maintenance/repair	Shall have equipment maintenance schedule and arrangements for minor repairs
Operational records	Operational records shall include quantity of waste received and disposed, vehicles records etc., required by statute and operation
Project specific activity	Tree sapling plantation, awareness, corporate social responsibility shall be considered
Regulatory issues	Shall take measures to fulfil all statutory requirement
Safety and security issues	Shall take measures to fulfil adequate safety and security requirement
Salvage	Need to be done or avoided depending on local condition.

Table 5.5 Factors to be considered during post closure of landfill

Factors	Remarks
Environmental monitoring	Shall be done up to twenty years and beyond based on project and local regulation
Landfill gas ventilation/leachate treatment	Shall be done to avoid environmental degradation
Post closure maintenance	Arrangement shall be made for lawn/drainage/ lighting etc.
Safety and security	Need to be done to safe guard people and animals

The decomposition of biodegradable waste happens in five stages. In the first stage, aerobic bacteria produce CO_2, water and heat. CO_2 may be released as a gas or absorbed by water to form carbonic acid contributing acidity to leachate. In second stage proteins, carbohydrates and lipids hydrolyzed by facultative bacteria to sugars. Sugars are further decomposed to CO_2, hydrogen, ammonia and organic acids. In third stage organic acids will be converted into acetic acid (CH3COOH), H_2, CO_2, H_2S. In the fourth stage methanogenic microorganisms degrade the organic acids to CH_4, CO_2, CH_4 and H_2O. In the final stage, CH_4 generated will be converted to CO_2 and H_2O. H_2S gas may also formed in final stage if contains high concentration of sulphates.

LFG generation is influenced by several factors: (1) the gas migration properties through the waste layers and top layer of the landfill, (2) gas collection efficiency, (3) CH_4 oxidation activity, (4) pH, (5) composition of waste, (6) temperature, (7) water content, (8) shredding, (9) compaction, (10) leachate recirculation, (11) meteorological condition (Mohammed et al. 2009; Cernuschi

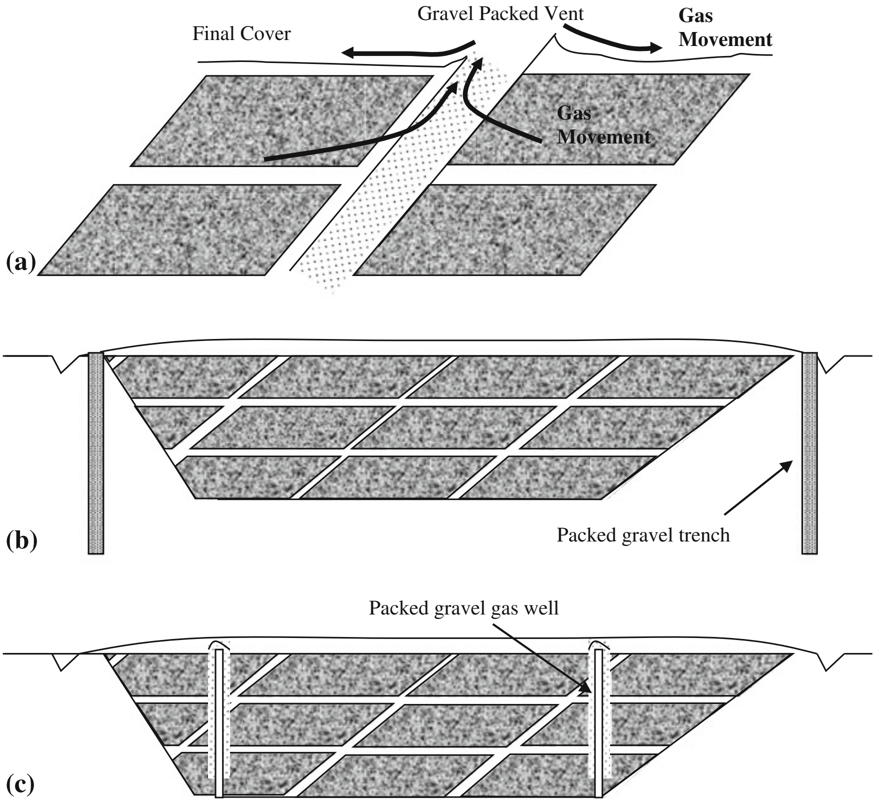

Fig. 5.10 Usual methods of venting landfill gases: (**a**) cell, (**b**) barrier, (**c**) well

and Giugliano 1996; Christensen et al. 1996; Gurijala et al. 1997; Naranjo et al. 2004; Sormunen et al. 2008; Tecle et al. 2008; Williams 2005; Zhang et al. 2008).

90 % of LFG contains methane and carbon dioxide. Although most of the methane escapes into the atmosphere, they can also move laterally. If the LFG is not vented out properly it will accumulate below buildings or other spaces as its specific gravity is less than air.

Carbon dioxide is about 1.5 times denser than air and 2.8 times denser than methane. Hence it will move towards the bottom of landfill and lowers the pH if enters groundwater thereby increasing hardness and mineral contents of the water. Therefore it is essential that movement of LFG be controlled by constructing vents, barriers and recovery. Gases generated from a landfill are either vented (Fig. 5.10) to the atmosphere or collected for power generation (Fig. 5.11).

Methane (CH_4) gas is important GHG as its global warming potential is more than carbon dioxide (CO_2) (Ishigaki et al. 2005). Concentration of atmospheric methane has more than doubled over the past 150 years (Stern et al. 2007). LFG is known to be generated both in managed “landfill” and “open dump” sites because of un-aerobic decomposition of organic matter in waste. It consists of 50–60 %

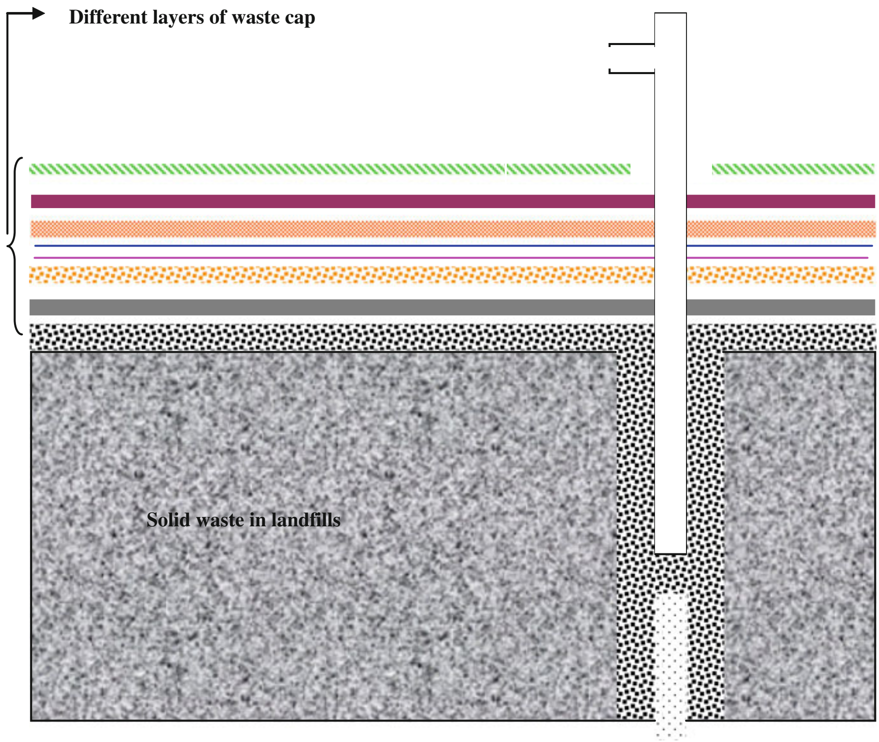

Fig. 5.11 Gas collection system in landfill

methane and 30–40 % of carbon dioxide and other gases in trace amount (Wang-Yao et al. 2006). Landfills are the main source of methane emissions in US and emitted nearly 37 % of total US carbon emissions in 1997 (EPA 1999).

As the production of methane will begin immediately after waste, "bio-tarp" can be used as a means to mitigate methane from open landfill cells. These bio-tarps also serve as a substitute to daily cover during landfill operation. Multilayered bio-tarp comprising of alternative layers of two geotextiles is capable of removing 16 % of the methane passing through the bio-tarp and addition of landfill cover soil/compost/shale amendments to the bio-tarp would increase the methane removal up to 32 % (Bryn et al. 2011).

Traditional cover material reduces the storage capacity. As per the studies conducted by Zezhi et al. (2011) intermediate covering system using high-density polyethylene (HDPE) geomembrane increases gas flow by 25 %. However, setting up of a high permeability layer near surface of landfill improves LFG collection efficiencies. The permeable layer would lessen the influence of cracks in the covering material on O_2 intrusion and CH_4 emissions promoting uniform and greater CH_4 oxidation in the cover layer.

Combustion is the common technique for controlling as well as treating LFG. The most common combustion technologies are flares, boilers, gas turbines, incinerators as well as internal combustion engines. Combustion will typically ensure more than 98 % destruction of organic compounds. During combustion methane is converted to carbon dioxide there by reducing impact due to release of GHG. At methane concentration of more than 20 % by volume, the LFG will form a combustible mixture with air in atmosphere and only an ignition source is required for operation. If the methane in LFG is less than 20 % methane by volume, additional fuel like natural gas will be required to operate flares. Flares can be open flame flares or enclosed flame flares. Open flame flares comprises of a pipe through which the LFG is pumped, a source of spark, and a mechanism to regulate the gas flow. The main disadvantages of open flame flares include inefficient combustion, poor aesthetics and monitoring difficulties. In enclosed flame flares gas and air entering is controlled, making combustion more efficient and reliable.

Landfill in most of developing countries is not properly constructed and heaped in open dumps leading to generation of methane gas. Most of developing countries receive good precipitation which makes decomposition slow leading to anaerobic condition. Hence in modified landfill method termed as Fukuvoka method leachate is collected through perforated surrounded in graded boulders pipe thereby introducing an aerobic condition. As leachate is removed earliest possible time the internal waste layer will have lower moisture contents leading to early stabilization of waste.

5.1.2.1 Monitoring of Landfills

Landfill monitoring is carried out for: (1) leachate quantity and quality, (2) leakage through liner, (3) groundwater quality, (3) ambient air quality, (4) gas in the surrounding soil, (5) landfill-gas quality and quantity, and (6) stability of the final cover.

Leakage through liner is usually detected using a lysimeter. Groundwater monitoring is accomplished through drilling monitoring wells around land fill. Gas extraction wells are be placed to collect any landfill gas.

5.1.2.2 Closure of Landfills

The land filled waste is covered with daily covers to form cells. But in practice it may not happen in many places. The waste heap is covered with liners to protect waste from rain (Fig. 5.12). Once the land fill size attains limit of capping the waste is covered with layers of geomeberane, clay, gravel, geotextile and top soil (Figs. 5.13 and 5.14).

Landfill closure and *postclosure* care are necessary for 30–50 years after capping to ensure safety and avoid damage to environment. A closure plan should include land scaping, runoff control, gas and leachate collection and treatment, erosion control, and environmental monitoring.

Fig. 5.12 Protection of solids filled in landfill from rain prior to capping

Fig. 5.13 Layering of cover soil on landfill

Fig. 5.14 Covering clay with topsoil in landfill cap

Postclosure care shall include routine inspection and plan for remedial if unacceptable levels of emissions and leachtes are observed during monitoring.

A final cover system shall be placed after completing of land fill to: (1) minimize infiltration of rainwater, (2) avoid fugitive emission, (3) to separate waste from environment, (4) minimize soil erosion, (5) minimize frost, (6) resist burrowing animals, (7) resist penetration of roots.

The permeability of the final cover shall be less than the underlying liner in order to prevent the "bathtub effect" wherein water infiltrate through the cover system and are contained by liner system increasing the hydraulic head on the liner system.

The final cover system consists of an infiltration layer of about 50 cm inches of earthen material covered by 15 cm soil capable of supporting native plant growth. An alternative cover design can be used if the cover guarantees protection against infiltration and erosion.

Even though not an economical option, welded HDPE geomembrane of at least 2.5 mm thick in intimate contact with a mineral layer is the generally desirable in sealers for landfill capping (August 1992; August and Tatzky-Gerth 1991; August and Tatzky-Gerth 1992; August et al. 1992; Müller and Lüders 1995; Meggyes and McDonald 1995; Meggyes et al. 1998; Müller 1993; Müller 1995; Müller et al. 1995).

Post-closure care activities involve maintaining the integrity and effectiveness of final cover system, groundwater monitoring system, LFG gas monitoring system, and leachate collection system.

Landfill capping shall have following components:

Surface vegetation: Vegetation helps in erosion of capping material. It will pose danger if there is penetration of deep roots into landfill.

Reclamation layer: This layer supports vegetation as well as protects the lower layers. Its thickness is determined by the depth of frost and root penetration (Rettenberger 1988; Jessberger H 1990).

Drainage layer: This layer has to divert the water penetrating through the reclamation layer. Hence it should have sufficient permeability for the purpose. Gravel, sand, glass ash, and incineration slag. Water collection is achieved using HDPE/PVC pipes.

Protective layer: Mineral layers or geotextiles are used to protect the geomembranes (Müller and Müller 1993).

Sealing layer: The sealing layer is provided to prevent rain-water percolation into the landfill and escape of landfill gas into the atmosphere. This layer is made up of polymer sheeting (known as geomembranes) or clayey materials or asphaltic liners or bentonite mats.

Regulating layer: This layer is used to separate the capping from the waste and provide a base for the compaction of the sealing layer.

Gas drainage layer: The gas drainage layer shall collect LFG generated from landfill and is made up of material stones or gravel.

5.1.3 Operation of Landfills

Operating precautions include control of the size cells, placement of interim cover, and use of proper storm water drainage controls. The movement, positioning, and compaction of solid waste and cover in landfill need a variety of big machines like tractors, loaders, compactors, motor graders, hydraulic excavators, fire extinguishing vehicles, water trucks, and service vehicles. Specially built landfill compactors are now used in most of the landfills in developed countries. Daily cover is excavated and placed using pans or scrapers. At an active landfill, solid waste wastes are placed in layers on the liner and leachate-collection system. Precaution should be taken not to place any compatible material adjacent to each other in hazardous landfill sites.

Waste in the lowermost layers shall be free from sharp objects to avoid puncturing of liners. The waste must be placed in such a way that equipments do not damage the leachate-collection system. Filling shall begin in a corner and move outward. The filling sequence shall be established at the design stage. Waste shall be covered at the end of every working day with soil or alternative daily cover (like textiles, geomembrane, or other proprietary materials) to control vectors and rodents; to reduce odor, litter, and air pollution; to reduce the risk of fire; and to reduce leachate production.

Run-on in landfill area can be prevented by deviating storm water from active landfill areas. The landfill sides should be sloped to achieve slope stability. Facility must be capable of handling maximum storm water generated in single day in past 25-years. Typical measures to manage run-off include contouring the land adjacent the landfill cell and constructing ditches, dike/culverts to divert flow.

5.1.4 Use of Old Landfill Sites

Closed landfill sites can be used for other purpose like golf courses, recreation parks, ski slopes and parking lots.

The closed landfill site is subjected to differential settlement, LFG generation, leachate generation. Settlement occurs rapidly in the first 1–12 months. This period of primary settlement is followed by secondary settlement which occurs 15–20 years after primary settlement. The rate and extent of settlement depends on land filled waste.

5.1.5 Landfill Mining

Digging up old landfills to separate the non-biodegradable material is called landfill mining. The non-biodegradable fraction can be reused and finer fraction can be used as cover material for landfills. Opening the cap of landfill may result in the escape of landfill gas to the atmosphere and produce contaminated runoff during rains.

5.1.6 *Land Filling Hazardous Waste*

The land filling hazardous waste is different from the MSW as the hazardous waste will have no compatible material which may result in heat, explosion and other undesirable reaction if not properly pre-treated and stabilised. Unlike the MSW, the hazardous waste needs tracking and recording which extend to locations within the disposal site. Records shall include source of waste and characteristics of waste so that remedial action could be taken place some day in future when undesirable events occur resulting in ground/surface water contamination. The tracking of waste also helps in ensuring waste compatibility.

The detailed discussion of land filling hazardous waste is done in Chap. 7.

5.2 Co-Processing of Solid Wastes

Co-processing is the use of waste in industrial processes. Generally 30–40 % of the production cost (excluding capital cost) in an industry is spent on energy usage. Use of waste is becoming more popular to fulfil energy requirement and cut production cost. Figure 5.15 shows waste stored in a cement manufacturing facility for co-processing.

Co-processing waste has the following advantages in cement industry:

- The alkaline conditions favour the absorption of volatile matter from the gas phase.
- The reactions of clinker at 1,450 °C allow chemical binding of ashes to the clinker.

Co-processing will have the following problems associated with it

- Concentration of hazardous substances should be done above 1450 °C and at residence time of over two seconds to avoid formation of dioxins and furans, and
- Melted plastic can hamper or block the substance flow from the pre heater to the cement kiln in case high plastic materials are present in the feed.

Fig. 5.15 Waste stored in a cement manufacturing facility for co-processing

5.3 Incineration and Waste to Energy

Incineration is one of the most widely used methods used to dispose all combustible waste. Combustion process results in air pollutants and needs to be controlled. Incineration is less practised in the developing countries due to high capital/operating costs. As per (Psomopoulos et al. 2009), the USA has over 1,500 incinerators out of which 87 are Waste to Energy (WTE) plants and operating these WTE by burning nearly 26.3 million tons of MSW serve a population of 30 million.

Incineration is a waste treatment/disposal wherein waste is burnt in specialized engineered set up. Incineration is also called "thermal treatment" as it involves heat to obtain a desired result. Combustion converts the waste into ash, flue gas, and heat. The flue gases must be fitted with air pollution control equipment to avoid impact of air pollution on environment.

Energy from an incinerator can be recovered for industrial purpose. Incinerators reduce the combustible material by 80–85 % of the initial mass. In order to avoid air pollution due to possible emission of intermediate combustion products like dioxins and furans the air from solid combustion chamber is made to enter a secondary chamber wherein the gas is subject to high temperature. The temperature of the primary chamber shall be maintained at 800 ± 50°C from where the gases enter the secondary chamber maintained at 1,050 ± 50°C where gas residence time shall be at least 1 (one) sec with minimum 3 % (w/w) oxygen in the stack gas.

Waste-to-energy combustion has recently slowed due to issues like flow control, impact on recycling, cost effectiveness, as well as to political acceptability.

The term Refuse Derived Fuel (RDF) is usually used for the segregated fraction of MSW with high calorific value. Other terms used for MSW derived fuels are Recovered Fuel (REF), Paper and Plastic Fraction (PPF) Packaging Derived Fuels (PDF), and Process Engineered Fuel (PEF). Terms 'Substitute Fuel Secondary

Fuel and Substitute Liquid Fuel (SLF) are used for processed waste from industries. The total RDF from processed MSW used for energy installations, power plants, district heating plants and industries is more than 2 million tpa in European Union.

RDF is incinerated as well as co-incinerated in Scandinavian countries in district heating plants. MSW is used as RDF in cement kilns after sorting and balling in Austria, Belgium, Denmark, Italy and Netherlands.

5.3.1 Heat Value of Refuse

The heat values of waste are necessary for making decisions about disposal options. The heat values of waste can be measured with a calorimeter. In the absence of calorimeter the calorific value can be estimated in accordance with the example in Box 5.1.

The success of a waste incineration project depends on accurate data about the future waste quantities and characteristics. The lower calorific value (LCV) should be above a minimum level. The specific composition of waste is also important. Combination of tyres and C&D waste is not suitable even if the average LCV is relatively high. In order to operate incinerator continuously, waste availability must be stable through the year. Hence, the seasonal variations of characteristics and LCV must be established before launching the project. Waste composition depends on cultural differences, socio-economic conditions and climate. Hence, the data of one place cannot be used at another place. The effect of recycling and rag picking which change the composition of MSW must be considered prior to finalization of waste conversion to energy. In many countries the moisture or ash content (or both) in the waste will be high. Waste from commercial (with exception like fish/meat/vegetable/fruit market) and industrial activities have a much higher LCV than domestic waste. Waste from demolition and construction activities which contain hazardous or explosive material are not suitable for incineration.

The waste composition will also change in time due to additional recycling or economic growth. Such changes can alter the quantity of waste and LCV. The average LCV of the waste should be at least 6 MJ/kg during all seasons and the annual average LCV should not be less than 7 MJ/kg (World Bank 1999).

As per the actual operating data collected in the US on the average, incineration of one metric tonne of MSW in a modern Waste to Energy power plant produces a net of 600 kWh of electricity thereby avoiding importing one barrel of oil or mining a quarter tonne of high quality US coal (Psomopoulos et al. 2009). But still new WTE facilities were established in the USA between 1996 and 2007 due to environmental and political pressures. The main environmental concern in this regard was the perceived release of toxic substances into the environment.

Box 5.1 Combustion chemistry of waste

As discussed earlier carbon, hydrogen and sulphur are major elements of most of the waste components in municipal solid waste. Even in case of hazardous waste or biomedical waste combustibility of the matter depends on availability of carbon, sulphur and hydrogen. In the absence of this material in appreciable quantity combustion would not take place and need to be disposed in different method other than incineration. Combustion is the process of generation of energy during following major reactions.

$$C + O_2 \rightarrow CO_2$$

$$(12)\,(32)\,(44)$$

$$2H_2 + O_2 \rightarrow 2H_2O$$

$$(4)\,(32)\,(36)$$

$$S + O_2 \rightarrow SO_2$$

$$(32)\,(32)\,(64)$$

The numbers in parenthesis are molecular weights.
Considering oxygen content of air to be 23.15 % by mass,
Amount of air required for total oxidation of 1 kg of carbon is

$$(32/12)(1/0.2315) = 11.52\text{kg}$$

Amount of air required for total oxidation of 1 kg of hydrogen is

$$(32/4)(1/0.2315) = 34.56\text{kg}$$

Amount of air required for total oxidation of 1 kg of sulphur is

$$(32/32)(1/0.2315) = 4.32\text{kg}$$

It is assumed that oxygen in waste will be combined with hydrogen in the waste to from water.

Example of air requirement

For example after performing proximate analysis of waste if the chemical formula of waste is $C_{40}\,H_{100}\,O_{40}\,S$

The molecular mass = (40 x 12) + (100 x 1) + (40 x 16) + (1 x 32) = 1252

Percentage distribution of basic elements

Element	Calculation of percent by mass	Percent by mass
Carbon	(40 x 12/1252)100	38.34
Hydrogen	(100 x 1/1252)100	7.99
Oxygen	(40 x 16/1252)100	51.12
Sulphur	(1 x 32/1252)100	2.56

Net available hydrogen = (7.99−51.12/8) % = 1.6
Air requirement

Element	Calculation of air requirement	Air requirement (kg/t)
Carbon	(0.3834 x 1000)11.52	4416.77
Hydrogen	(0.0160 x 1000)34.56	552.96
Sulphur	(0. 0256 x 1000) 4.32	110.59
Total		5080.32

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5.3.2 *Combustion and Energy Recovery*

Use of waste for energy is as old as invention of fire itself. All over the world the waste material with sufficient calorific value is used as fuel either for cooking or heating. In many countries cow dung is used as fuel after it is dried in the form of briquettes (Fig. 5.16). The waste from wood processing like wood chips and saw dust was also used as fuel. With the civilization leading to more and more urbanization, there was priority shift in the communities. Instead of living in single houses people chose to live in multistoried building wherein burning waste or solid fuel is limited due to safety reason, there by generating huge quantity of waste from highly populated cities.

The first effort to dispose of solid waste with furnace is believed to have happened in England in the 1870s (Waste Online 2011). The most common methods of MSW management are biological treatment, land filling, composting, mechanical treatment, recycling, and waste-to-energy (WTE). The USA had 88 WTE plants that burn about 26.3 million tonnes of MSW (Psomopoulos et al. 2009) in 2009. More than 90 % of WTE facilities in Europe use mass burn incineration technology and the largest WTE facility treats approximately 750,000 tpy (Thomos 2004). Use of biomass residues as fuel in ceramic furnaces was studied by (José Edmundo et al. 2011) and observed economic feasibility. As per Simmons et al. (2006), about 7.7 % of the total MSW was processed for energy recovery.

5.3.3 *Energy Production from Waste*

With global sucrose production of approximately Mt 1,500 per annum bagasse represents a prospective energy source of 3.8 x 10^9 Gigajoules (Stanmore 2011).

Fig. 5.16 Fuel briquette made out of waste

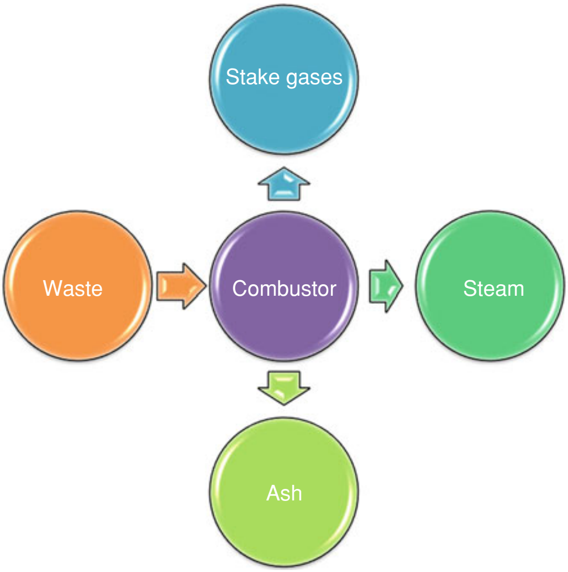

Fig. 5.17 Material balance in waste incineration

5.3.4 *Material and Thermal Balances*

It is necessary to assess the heat material and thermal balance of the combustor prior the project. The material entering the system and coming out the system is shown in Fig. 5.17.

The materials entering or leaving the system can absorb or release heat and is schematically depicted in Fig. 5.17. Waste as well as subsidiary fuel material releases the heat whereas water and air entering the system will absorb the heat. Ultimately heat will be transferred to steam, ash and air coming in contact with hot surface. Hence, the heat transferred to ash and air will not be economically useful

Fig. 5.18 Thermal balance in an incinerator

and considered as losses. Hence the heat loss in stack emission, ash has to be considered along with heat loss due to radiation Fig. 5.18

Heat released during combustion of solid wastes is partially stored in gases and ash. The rest of the heat will be transferred by convection, conduction and radiation to the incinerator walls as well as the incoming waste. The unburnt carbon usually contains 4–8 % unburnt carbon. The heat loss through the reactor as well as other appurtences to the surroundings will be around 0.003–0.005 kJ/kg of furnace input (Howard et al. 1986). The latent heat of vaporization for water is about 2420 kJ/kg. Apart from these there would be some heat lost with residue and stack gases. In order to ensure economics of the operation it is desirable that: (1) carbon, ash, moisture content in the waste be maintained properly and (2) temperature of exhaust gas in the stack be within predetermined temperature range.

5.3.4.1 Waste Heat Recovery

The furnaces walls of combustors are lined with tubes through which water is circulated to recover heat. The steam generated in this process is used for driving turbines or other industrial purpose. In the process hot air entering the chimney carries heat which can be further recovered by passing the hot air through metal pipes carrying water. Waste heat recovered can be used for preheating the water entering the furnace or for industrial purpose.

5.3.5 Other Technologies

A variety of thermal processes like incineration, melting, pyrolysis, or vitrification have been used for disposal of waste with an aim to reuse advantageously or dispose ultimately in an inert landfill (Colombo et al. 2003; Sabbas et al. 2003; Kuo et al. 2006).

Treatment of waste by thermal plasma technology is being practiced in some places as it does not emit much air pollution and will not generate much ash. Plasma is the fourth state of matter, comprising of electrons, ions and neutral particles. Molecules will dissociate into the atoms at 2,000 °C and will get ionised at 3,000 °C. Plasma technology involves the formation of a continuous electrical

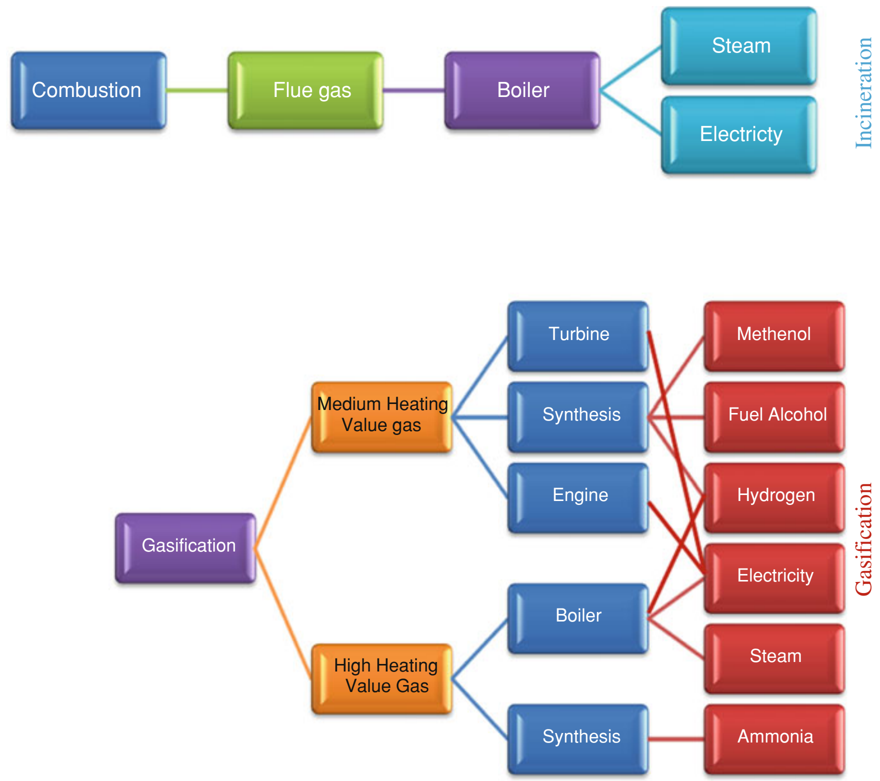

Fig. 5.19 Comparison of incineration and gasification with respect to flexibility

arc by the passing electric current through a gas. The process of passing of electric current through a gas is called electrical breakdown. Significant heat is generated in the process which separates electrons from the gas molecules and forming ionised gas stream, or plasma.

Thermal plasmas have many advantages including high intensity, high temperature, high energy density and non-ionising radiation. While burning fossil fuel can achieve only 2,000^{o} C, electrically generated thermal plasmas can attain a temperature of 20,000 ^{o}C or more and thermal gradients can be controlled autonomously of chemistry.

Thermal plasma reactors offer high throughput through compact reactor geometry but has a disadvantage of use of electrical power as source of the energy. Thermal plasmas for waste treatment are generated by electrical currents up to 1×10^{5}, radio frequency (RF) and microwave discharges and laser-induced plasmas.

Thermal plasma reactors have following advantages during destruction of hazardous wastes: (1) fast reaction times, (2) large throughput, (3) small reactor footprint, (4) reduces formation of persistent organic pollutants (POPs), (5) can be used for a wide range of wastes, (6) rapid start-up and shutdown times, and (7) no requirement of oxidants Fig. 5.19.

Nanomaterials like cellulose, chitin and starch, often called whiskers, could be easily extracted from waste. Nanobiocomposites have the potential to substitute current petrochemical-based materials due to the high demand for green technology and represent an element waste disposal strategies in the future. Waste from shellfish processing industry represent about 30-wt % in chitin. Worldwide nearly 105 t/year of chitin is manufactured from shrimp and crab waste material for industrial uses (Visakh and Sabu 2010). Chitin has found applications in many areas other than food such as in biosensors (Krajewska 2004).

5.3.5.1 Gasification

Gasification is one of the emerging biological technologies. Gasification can be applied to convert organic waste to low calorific gas. Gasification is usually followed by combustion of gasses generated in a furnace or internal combustion engines or gas turbines after cleaning of the product gas.

In the gasification process coarsely-shredded waste enters a gasifier wherein the carbonaceous fraction of the waste reacts with a gasifying agent like oxygen, steam or carbon dioxide. Sometimes the gasifier is fed with paralyzed waste. The process takes place at about 800–1,100 °C depending on the calorific value and chemical reactions. Fixed carbon is also gasified in the gasification process.

There are three types of gasification technologies namely fixed bed, fluidized bed in addition to high temperature gasification. Among these methods, high temperature method is used widely.

5.3.5.2 Plasma Technology

Plasma is a group of free-moving electrons and ions formed by applying a high voltage across a gas at reduced or atmospheric pressure. Incinerators usually use controlled flame for combustion whereas plasma-arc technology uses an electric current which passes through a gas (air) to create plasma.

When plasma gas passes on waste, it causes speedy breakdown of the waste into syngas which is a gas mixture that contains varying quantity of carbon monoxide and hydrogen.

5.3.5.3 Pyrolysis

Pyrolysis is thermal processing in total absence of oxygen. As landfill and incineration become more expensive, emphasis is being given to new disposal options. Pyrolysis is a thermo-chemical decay of organic substance in the absence of oxygen at elevated temperatures. Pyrolysis is a method for the treatment in order to decrease leaching and emissions to the environment (EEA 2002). Organic waste are thermally degraded to produce useful liquid hydrocarbons, which can then added to fuel or solvent product, or returned a refinery where it is added to the feed stocks. Process can be carried out in vacuum in which is referred as vacuum pyrolysis. In flash vacuum thermolysis, the residence time of the substrate at the working temperature is restricted as much as possible, to minimize secondary reactions.

In this process waste shredded and fed into a reactor is operated in the absence of oxygen under atmospheric pressure at 500–700 °C for 0.5–1 h. The process is referred to as thermolysis if the temperature is 500 °C or less.

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Chapter 6
Biomedical Waste

Biomedical waste comprises of all liquid and solid wastes generated from medical establishments and activities involving biological materials. Besides health care, the relevant activities include clinical research, research involving animals, animal farms, dead animals, and others. The generation of biomedical waste is not restricted to specific activity or organisations. It can originate from homes during dialysis and using insulin injections, animal health activities in rural areas, butchering of sick animals in butcher houses, medical shops, use of sanitary napkins and ear buds, use of diapers, and air ports when passengers through away restricted medicines without prescription.

Many countries do not have separate regulation and mechanism to manage biomedical waste. Among those which have adopted separate legislation have different definition with respect to biomedical waste.

For example, as per the Biomedical Waste (Management and Handling) Rules (1998) of India, "Biomedical waste" means

> any waste, which is generated during the diagnosis, treatment or immunisation of human beings or animals or in research activities pertaining thereto or in the production or testing of biologicals, and including categories mentioned in Schedule I

The schedule I of the above rule comprises of waste category, human anatomical waste, animal waste, microbiology and biotechnology wastes, waste sharps, discarded medicines and cytotoxic drugs, soiled waste, solid waste (wastes generated from disposable items other than the waste sharps), liquid waste, incineration ash, chemical waste.

The legal document Order No. 242/96 dated 13 August 1996 Portugal clinical waste includes all the waste generated by health-care establishments, research facilities, and laboratories are grouped into four classes (Pa'ssaro 2003):

Group I—not subject to special treatment,
Group II—not subject to special requirements in its treatment,

R. Chandrappa and D. B. Das, *Solid Waste Management*,
Environmental Science and Engineering, DOI: 10.1007/978-3-642-28681-0_6,

Fig. 6.1 Biomedical waste stored unscientifically for recycling

Group III—comprises of contaminated wastes, *or potentially contaminated waste*, *and*
Group IV—wastes that must be incinerated

Clinical waste is defined in regulation 1(2) of The Controlled Waste Regulations 1992 (SI1992/588) of United Kingdom as follows:

1. any waste which consists wholly or partly of human or animal tissue, blood, other body fluids, excretion, drugs or other pharmaceutical products, swabs or dressings, or syringes, needles or other sharp instruments, being waste which unless rendered safe may prove hazardous to any person coming into contact with it, and
2. any other waste arising from medical, nursing, dental, veterinary, pharmaceutical or similar practice, investigation treatment, care, teaching or research, or the collection of blood for transfusion, being waste which may cause infection to any person coming into contact with it.

The Medical Waste Tracking Act (1988) of the United State of America (USA) makes administrator of the act in each state to promulgate regulation listing the type of medical waste. This has resulted in the inclusion of an elaborate list of medical wastes by individual authorities responsible under the act in each state.

Biomedical waste management is influenced by social, cultural and economic circumstances. About 10–15 % of waste from hospital are considered ''infectious'' (USC 1988). Figure 6.1 shows biomedical waste stored unscientifically for recycling. The risky wastes comprising of infectious/toxic/radioactive substances can contaminate the non-risky wastes resulting in huge quantity of risky wastes demanding costly treatment and disposal options.

Enforcement of rules pertaining to biomedical waste in developing countries are difficult for the following reason: (1) quacks in professions, (2) profession being practiced by numerous doctors from home and garage without formal trade license, (3) practice is intentionally not registered in any government organization to avoid income tax, (4) attitude of health care professionals to discard as it is and where it is, (5) pressure to increase profits, (6) poor law enforcement by local bodies which can take action for causing nuisance, (7) the behaviour of waste throwing is deep registered in unconscious mind, and (8) lack of importance given for education in waste management.

The health care sector in the developing countries is a mixed bag with ownership lying in the hands of doctors, quacks, non-medical professionals, government, doctors operated for profit, and charity. The profession does not attract as many laws as other industries. People do not negotiate for the service received by health care establishments a reason which is sufficient for many entrepreneurs to establish hospitals whose only motive is profit. People in the neighbourhoods do not complain about doctors as they have to maintain relation with doctors as they are needed in emergency.

The main characteristics of biomedical waste are: (1) disinfection nearest to source, (2) mutilation often disinfection at the earliest opportunity, (3) does not affect individual or environment, and (4) a solution does not become problem.

6.1 Significance

Healthcare establishments have particular responsibilities with respect to the wastes they generate (Pruss et al. 1999). However, the impact of biomedical waste has not been given significant attention often (Saurabh et al. 2009). Negligence in biomedical waste management contributes to environmental pollution, sickness of humans/animals, and depletes natural as well as financial resources (Henry and Heinke 1996; Oweis et al. 2005).

The evolution of biomedical waste as a separate category of waste dates back to the late 1970s, when medical wastes were found on the beaches in the east coast in the USA. This followed enactment of the US Medical Waste Tracking Act (MWTA) in 1988.

Biomedical waste, if not managed properly, will pose significant environmental and health impact. The grave health hazards posed by the poor handling of biomedical waste to the hospital staff, rag-pickers, municipal workers and the community have been well, documented. In many developing countries, an overall management of the biomedical waste is still an exception and not a rule. Lalji et al. (2008) recommend monitoring and legal action as significant steps in the management of biomedical wastes.

In spite of the intrinsic impacts, treatment and disposal of biomedical waste remain a negligent activity resulting in pathogens entering in food due to mixing of infectious animal waste with meat. It is also a common practice in many developing countries to supply meat derived from animals with infectious diseases which in turn may contaminate food with which it comes in contact.

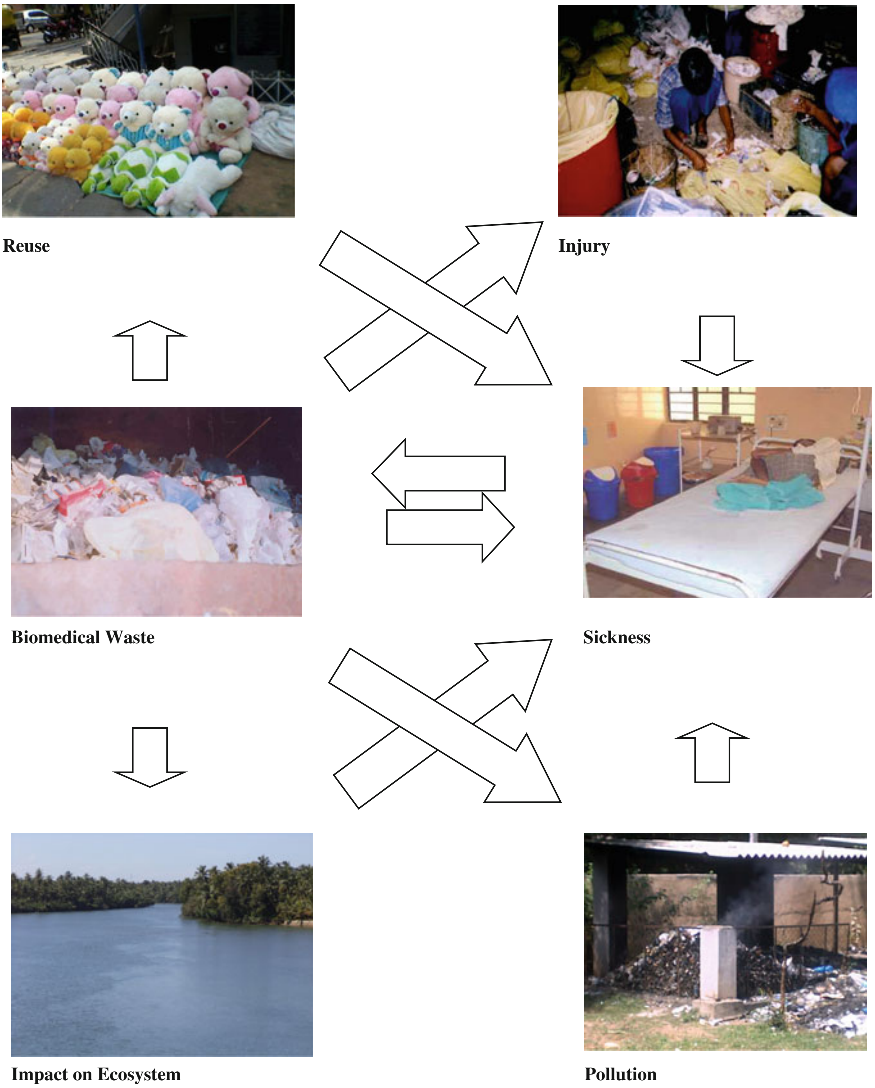

Fig. 6.2 Consequences of indiscriminate biomedical waste disposal

Figure 6.2 shows some consequences of indiscriminate biomedical waste generation. The hazardous nature of the biomedical waste is due to the following: (1) infection, (2) genotoxicity (deleterious action on genetic material of cell affecting its integrity), (3) toxicity, (4) exposure to radioactivity, (5) injury.

In many countries a number of contaminated waste materials like cotton, syringes, sharps re-enter the market either in the same or an altered form. Infected cotton may be used for making ear buds and toys. Syringes from waste are often repacked and sold as new packs.

Table 6.1 Examples of pathogenic virus and associated disease

Virus	Disease
Adenovirus	Colds
Arenavirus–Junin	Hemmorhagic fever
Arenavirus–Lassa	Lassa fever
Arenavirus–Machupo	Hemmorhagic fever
Coronavirus	Colds
Coxsackievirus	Colds
Ebola virus	Ebola hemorrhagic fever
Echovirus	Colds
Filovirus–Marburg	Hemmorhagic fever
Guanarito virus	Venezuelan hemorrhagic fever
Hantaanvirus	Hemorragic fever with renal syndrome (HRFS)
Hepatitis C	Parenterally transmitted non-A, non-B, liver infection
Hepatitis E	Enterically transmitted non-A, non-B hepatitis
HHV-8	Associated with Kaposi sarcoma in AIDS patients
HTLV-II	Hairy cell leukemia
Human herpesvirus-6 (HHV-6)	Roseola subitum
Human immunodeficiency virus (HIV)	Acquiredimmunodeficiency syndrome (AIDS)
Human T-lymphotropic	T-cell lymphoma-leukemia virus I (HTLV-l)
Monkeypox	Monkeypox
Morbillivirus	Measles (rubeola)
Orthomyxovirus–Influenza	Flu
Parainfluenza	Flu
Paramyxovirus	Mumps
Parvovirus B19	Fifth disease, anemia
Parvovirus Bl9	Aplasticcrisisinchronichemolyticanemia
Poxvirus–Vaccinia	Cowpox
Poliovirus	Poliomyelitis
Poxvirus–Variola	Smallpox (extinct)
Reovirus	Colds
Respiratory syncytial virus	Pneumonia
Rhinovirus	Colds
Rotavirus	infantile diarrhea
Sabia virus	Brazilian hemolrhagic fever
Sin nombre virus	Adult respiratory distress syndrome
Togavirus	Rubella (German measles)
Varicella-zoster	Chickenpox

Source Medical Air solutions (2011; Sylvane 2011; Anthony and Elizabeth 1981)

Tables 6.1, 6.2, 6.3 and 6.4 give examples of pathogens that are present in some typical biomedical wastes. Presence of the pathogens in substantial quantities would spread disease through air, water, food, vectors, rodents, touching, etc. Needle injury will result in sero-conversion (development of specific antibodies to microbes in the blood serum due to infection or immunization) with respect to Hepatitis C (HCV) and Human immunodeficiency virus (HIV).

Table 6.2 Examples of pathogenic bacteria and associated disease

Bacteria	Disease
Actinomyces israelii	Actinomycosis
Bacillus anthracis	Anthrax
Bartonella henselae	Cat-saatch disease, bacillaryangiomatosis
Bordetella pertussis	Whooping cough
Borrelia burgdorferi	Lyme disease
Campylobacter jejuni	Enteric pathogens distributed globally
Chlamydia pneumonia	Pneumonia, bronchitis
Chlamydia psittaci	Psittacosis
Clostridium tetani	Nonrespiratory airborne
Corynebacteria diphtheria	Diptheria
Coxiella burnetii	Q Fever
Ehrlichia chafeensis	Human ehrlichiosis
Enterobacter cloacae	Nonrespiratory airborne
Enterococcus	Nonrespiratory airborne
Francisella tularensis	Tularemia
Haemophilus influenza	Meningitis
Helicobacter pylori	Peptic ulcer disease
Legionella parisiensis	Pneumonia
Legionella pneumophila	Pontiac fever
Legionella pneumophila	Legionnaires' disease
Micromonospora faeni	Farmer's lung
Micropolyspora faeni	Farmer's lung
Mycobacterium avium	Cavitary pulmonary
Mycobacterium intracellulare	Cavitary pulmonary
Mycobacterium kansasii	Cavitary pulmonary
Mycobacterium tuberculosis	Tuberculosis
Mycoplasma pneumonia	Pneumonia
Neisseria meningitides	Meningitis
Nocardia asteroids	Nocardiosis
Nocardia brasiliensis	Pulmonary mycetoma
Nocardia caviae	Nocardiosis
Pseudomonas cepacia	Nonrespiratory airborne
Saccharomonospora viridis	Farmer's Lung
Salmonella Typhi	Typoid Fever
Shigella Dysenteriae	Bacterial Dysentry
Streptococcus pyogenes	Scarlet fever, pharyngitis
Thermoactinomyces sacchari	Bagassosis
Thermoactinomyces vulgaris	Farmer's Lung, hypersensitivity Pneumonitisis
Thermomonospora viridis	Farmer's Lung, hypersensitivity Pneumonitisis
Vibrio cholerae	Cholera
Yersinia pestis	Pneumonic plague

Source Medical Air solutions (2011; Sylvane 2011; Anthony and Elizabeth 1981)

Substitute products with less or non-hazardous materials or using technologies that generate less toxic/volume of waste (like precapsulated amalgam, non-hazardous biodegradable detergents, digital radiography, mercury free restorations,

Table 6.3 Examples of pathogenic protozoa and associated diseases

Protozoa	Disease
Balatidium coli	Dysentery, intestinal ulcers
Giardia lamblia	Diarrhea
Entamoeba histolystica	Amoebic dysentery, infections of other organs
Isospora belli	Intestainal parasites, gastrointestinal infection
Isospora hominis	Intestainal parasites, gastrointestinal infection
Pneumocystis carinii	Pneumocystosis

Source Medical Air solutions (2011; Sylvane (2011; Anthony and Elizabeth 1981)

Table 6.4 Summary of treatment and disposal options for biomedical waste

Sl. No.	Waste category type	Treatment and disposal option
1.	Animal waste	Incineration/deep burial
2.	Chemical waste	Treatment by chemical for liquids. Secured landfill for solids
3.	Genotoxic	Destruction/Incineration and disposal in secured landfills
4.	Incineration ash	Disposal in municipal landfill
5.	Microbiology and biotechnology wastes	Local autoclaving/micro-waving/incineration
6.	Pathological waste	Incineration/deep burial
7.	Pharmaceutical waste	Destruction/Incineration and disposal in secured landfills
8.	Pressurized containers	Return to suppliers/Controlled destruction
9.	Radio active waste	Concentrate and contain or dilute and disperse
10.	Sharps	Disinfection and mutilation/shredding
11.	Soiled waste	Destruction/incineration and disposal in secured landfills
12.	Waste with heavy metal	Heavy metal recovery

steam sterilization, X-ray system cleaners without chromium, etc.) would definitely help degradation of environment. Materials such as zinc, mercury, silver from amalgam and X-ray fixer and lead from film backing can be reclaimed/recycled using appropriate method.

Figure 6.3 shows a schematic diagram depicting a infection cycle with respect to biomedical waste. Many studies have proven that virus can survive in water for 9–10 months at 8 °C (Anthony and Elizabeth 1981). In fact pathogen life span varies widely. For example, Feline influenza (cat influenza) caused by *Herpes Virus* can stay in the environment for a day whereas *Calici virus* can stay alive for 8–10 days in the environment. *Parvovirus* which is responsible for *Feline infectious enteritis* can live on for 12 months in the environment. *Fline leukaemea virus* and *Feline immunodeficiency virus* die within hours once they are outside the host. Fline infectious peritonis can live up to seven days in cat litter (WFC 2011).

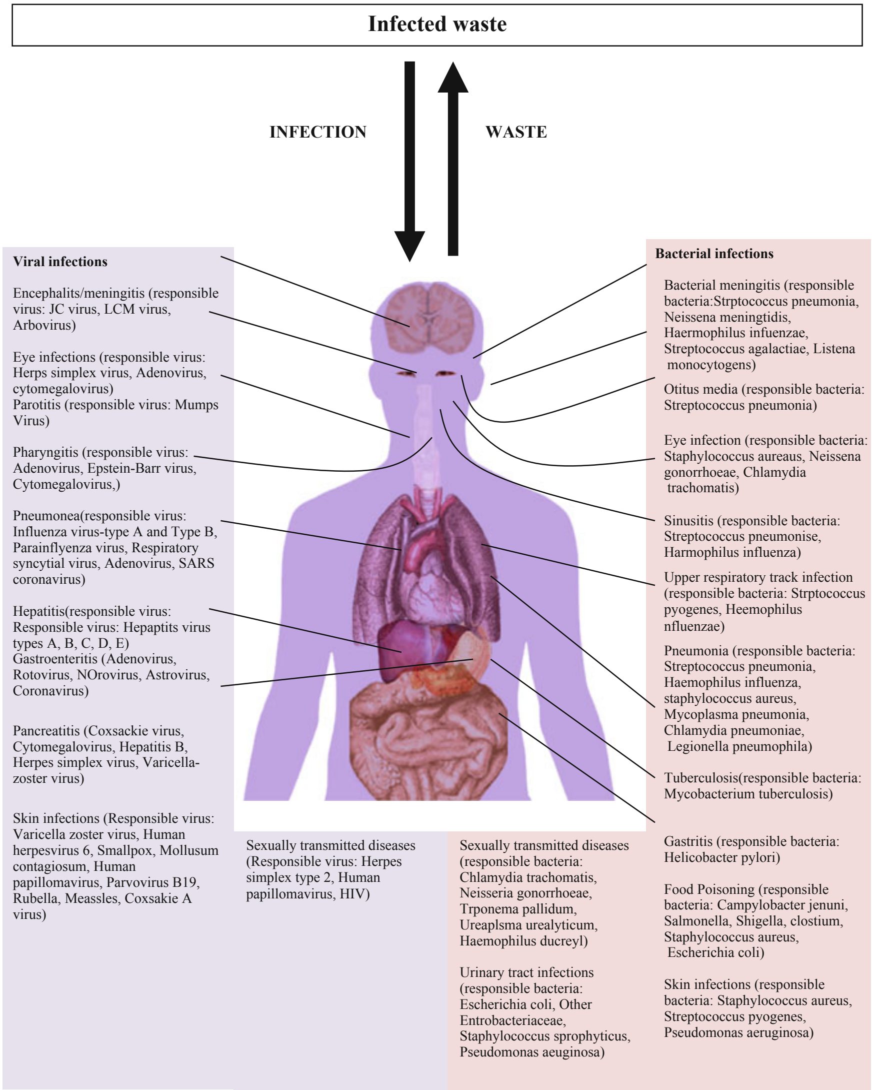

Fig. 6.3 Scematic diagram depicting infection cycle [*Source* Based on Medical Air solutions 2011; Sylvane 2011; Anthony and Elizabeth 1981]

According to the World Health Organization (WHO) estimation for the year 2001, infectious diseases resulted in 26 % of all deaths worldwide (Findhauser 2003). Nearly 40 % of these deaths were due to respiratory infections and diarrhoeal diseases. Existing drugs and vaccines, as well as providing access to good food and water, could have prevented much of these deaths.

The number of emerging pathogens has increased over the last 40 years. Six viral pathogens, were discovered in the 1970s, and in the 1980s, this number rose to seven, which included HIV. In the 1990s, the number rose to 20 which included hepatitis E, F and G, as well as the West Nile encephalitis virus (Desselberger 2003). Newly discovered pathogens in this decade include the new strain of the avian influenza virus and the SARS virus.

6.1.1 Household Biomedical Waste

Household biomedical waste (HBW) is a subgroup of biomedical waste commonly found in MSW and in wastewater streams. These special wastes originate in households and pose problems in their safe handling. They pose human health and environmental hazards. Examples of HBW include expired drugs, bandages, syringes, sanitary napkins, disposable diapers, expired cosmetics, blood stained cloths, used bottles of syrups/tablets/ear-drops/eye-drops, used ointment tubes, empty pain killer spray cans, contaminated meat, ear buds, dead animals, etc.

Many of these waste materials are categorized as biomedical because as they will have any or all of the following property: (1) infection, (2) contaminated with body fluids, (3) expired or active drugs.

The quantities of HBW vary from countries to countries and houses to houses. The quantities have been estimated to vary between 0 and 3 % of MSW by weight. The variability depends on development of a country and income of individual. HBW emit dixines and furans when burn at dump sites. Storm water can pick infection from HBW.

6.1.2 Biomedical Waste from Rural Area

It is often understood that the urban area is the origin of biomedical waste. Irrespective of whether a country is under developed or developed, the rural areas in the country do contribute to the biomedical waste in substantial quantities. Even though the impact may not be visible immediately, it would harm the health and environment over a period of time. The common biomedical waste in rural area includes placenta during animal birth, carcase of dead sick animals, intentionally killed rodents, expired drugs, waste generated in veterinary hospitals and incemation centres. Further the waste from aopsials in rural area and household biomedical waste discussed earlier can not be over ruled which include diapers, sanitary napkins, condoms, bandages. The impact of such practice will occur over period of time. But ignorance among the rural people often leads to improper disposal contaminating food items produced. Quantities are often not estimated and reported. The fly-tipping of biomedical waste from urban area and illegal burying would also cause for an accumulating of biomedical waste in the rural area.

6.2 Nosocomial Infection and Health Burden Due to Biomedical Waste

Nosocomial infections are infections that spread in the healthcare service unit in hospitals. This type of infection is also known as a healthcare-associated infection or hospital-acquired infection.

Infectious waste contains pathogens in significant concentration to cause sickness in susceptible hosts. Infectious waste includes stocks and cultures of infectious material from surgery/autopsies on patients with infectious sickness, laboratory work, waste that was in contact with infected animals/patients/substance.

Studies conducted in 55 hospitals of 14 countries in four regions (Europe, Eastern Mediterranean, South-East Asia and Western Pacific) showed an average of 8.7 % of patients in hospital had nosocomial infections. Over 1.4 million people throughout the world suffer from nosocomial infection (Health Canada 1997a). The highest frequencies of nosocomial infections occur in the Eastern Mediterranean (11.8 %) and South-East Asia Regions (10.0 %), with a occurrence of 7.7 % in the European and 9.0 % in Western Pacific Regions (Health Canada 1997b).

Major risks associated with poor waste management are: (1) nosocomial infections to patients/hospital staff/visitors due to poor waste management, (2) injuries from sharps to hospital personnel and waste handlers, (3) risk associated with hazardous chemicals to persons handling wastes, (4) risk of infection outside hospitals to general public and waste handlers, and (5) degradation of quality of water, air and soil.

Cross-transmission of infection from healthcare workers to patients has been explained in a variety of clinical settings (Malavaud et al. 2001; Munoz et al. 1999; Slinger and Dennis 2002; Weinstock et al. 2000).

Examples of disease spread by hospital waste include respiratory infections, gastroenteric infections, genital infections, ocular infection, skin infections, acquired immunodeficiency syndrome (AIDS), meningitis, haemorrhagic fevers, anthrax, septicaemia, viral hepatitis A, bacteraemia, candidaemia, viral hepatitis B and C.

6.3 Characteristics and Quantities

The quantity of biomedical waste differs from country to country and among individual health care establishments. While establishment offering only consultancy and prescription do not generate medical waste, the highly sophisticated hospital with serious infection control policy will generate huge quantity of wastes. While some hospitals use linen on examination tables others use *medical exam table paper*. Since paper used to spread on medical examination table is discarded after each use the quantity would proportionately higher.

Typical quantity of medical waste as published by the Institute for Ecopreneurship is 1.5 to 2.0 kg/bed/d for France, Belgium and England, 1.1 kg/bed/d for the USA, 0.01 to 0.2 kg/bed/d for Middle East, Asia and Africa, 0.25 to 1.13 kg/bed/d for latin America.

Trends reported by Pruss et.al. (1999) and Johannessen (1997) ranged from 3 kg/bed/d for Latin American countries, 3–6 kg/bed/d for Western Europe, 2.5–4 kg/bed/d for high-income Eastern Asian nations, 7–10 kg/bed/d for North America, 1.4–2 kg/bed/d for Eastern Europe nations, 1.8–2.2 kg/bed/d middle-income Eastern Asian nations, and 1.3–3 kg/bed/d for eastern Mediterranean nations.

Data compiled by Pruss et.al (1999) and Halbwachs (1994) indicated that high-income nation generate 1.1–12.0 kg/person/year, middle-income nations generate 0.8–6.0 kg/person/year and low-income nations generate 0.5–3.0 kg/person/year.

The average generation rates in Jordan ranged from 0.29 to 1.36 kg/bed/day, while in terms of patient numbers it is from 0.36 to 0.87 kg/patient/day (Hani et al. 2007). While the studies conducted by Fayez et al. (2008) in Jordan revealed generation rate ranges from 0.26 to 2.6 kg/bed.

Studies from Jasem and Hani (2007) revealed that the rate of waste generation in Kuwait is from 3.87 to 7.44 kg/bed/day. This waste consisted of 71.44 %of domestic waste, 0.76 % of sharps and 27.8 % of infectious/hazardous waste.

Pruss et al. (1999) recommend the following estimates for *preliminary* waste management: planning: (1) 15 % pathological and infectious waste, (2) 80 % general health-care waste, (3) 3 % chemical/pharmaceutical waste, (4) 1 % sharps waste, (5) less than 1 % other waste, like radioactive waste or broken thermometers.

Biomedical waste can be categorized into following categories:

Ash of incinerated biomedical waste: Incineration ash comprises of ash generated during incineration of biomedical waste.

Animal waste: Animal waste comprises of animal tissues, body parts carcasses, organs, bleeding parts, fluid, blood/experimental animals used in research, waste generated by animal houses, and veterinary institutions.

Chemical waste: Waste containing chemical substance, which includes film developer, laboratory chemicals, solvents, expired and no longer needed disinfectants, scrap amalgam, elemental mercury, undeveloped X-ray film, used X-ray fixer, condemned lead aprons lead foil and cleaning agents.

Genotoxic: Waste containing material with genotoxic properties, including antineoplasic and cytotoxic drugs, genotoxic chemicals. Genotoxic waste may have teratogenic, mutagenic, or carcinogenic properties. It leads to severe health problems inside hospitals and after disposal. Genotoxic waste includes cytostatic drugs, body fluid from patients treated with cytostatic drugs, and radioactive material. Cytotoxic (or antineoplastic) drugs are type of Genotoxic waste have the ability to kill/stop the growth of certain living cells. They are used in therapy of neoplastic (an abnormal new growth of tissue in animals or plants) conditions.

Microbiology and biotechnology wastes: Wastes from laboratory stocks/cultures or specimens of micro-organisms, human and animal cell culture and infectious agents from research/industrial laboratories, wastes from production of toxins, biologicals, devices and dishses used for transfer of cultures.

Pathalogical waste: Pathological waste comprises of human fetuses; tissues, animal carcasses, organs, blood, body parts, anatomical waste, blood and saliva-soaked materials, Extracted teeth without amalgam restorations and body fluids. In this category human or animal body parts are called anatomical waste. Some of the pathogens can be dangerous, as they could possess high pathogenicity and resistant to treatment (Askarian et al. 2004).

Pharmaceutical waste: This category comprises of discarded medicines like partially used ointments, syrups, tablets, expired drugs, and used massage oils.

Pressurized containers: Waste containing containers with pressurized liquids, powdered materials, or gas, like gas containers and aerosol cans.

Radioactive waste: Waste from radiotherapy or research laboratory which includes contaminated packages, glassware or absorbent paper, urine/excreta from patients treated/tested with radionuclides.

Sharps: Sharps are substance that could cause cuts/puncture wounds. It includes needles, scalpel, knives, blades, razors, scalpels, X-Acto knives, scissors, infusion sets, bone chips, saws, nails and broken glass. These are considered to be high risk waste as the injury caused by them while handling infectious waste and patient can result in deadly disease to medical or paramedical staff.

Soiled waste: Soiled wastes are substance contaminated with body fluids including cotton, soiled plaster casts, lines beddings, dressings.

Waste with heavy metals: Waste consisting of waste contaminated with heavy metals/derivatives such as waste thermometers, batteries and manometers.

Food waste infected by patient: Food waste which has come in contact with infected person.

Tips for avoiding generation of excess medical waste include: (1) reduce the generation of waste at the point of source, (2) sterilization and reuse of instrument, and (3) digitization of all clinical records.

6.4 Treatment and Disposal

Typical biomedical waste management steps are shown in Fig. 6.4 which are (1) segregation into various components, (2) waste handling and storage, (3) transportation, (3) treatment and disposal.

Rural areas and areas where service of common biomedical waste treatment and disposal facility (CBMWTDF) are not available Health Care Establishments (HCE) shall dispose through captive facility to avoid spreading of infection and toxicity.

A location for storage of biomedical waste should be earmarked inside the establishment generating such waste. Biomedical waste, in bags/containers, should be stored in a separate room, place or building of a size suitable to the quantities of waste generated. Unless a cold storage room is available, healthcare waste should

Fig. 6.4 Elements of biomedical waste management

not exceed 48 h during the winter and 24 h during the summer in warm climate regions, 72 h in cool season and 48 h in hot season in regions with temperate climate. *Radioactive waste* shall be stored in containers behind lead shielding and should be labelled depicting type of radionuclide, the date, and details of storage conditions required. *Cytotoxic waste* shall be stored away from other biomedical waste in secure location.

Segregation is carried out in biomedical waste management mainly following reasons: (1) to avoid contamination of non-infectious waste by infection, (2) to avoid entry of toxic waste like lead, mercury and radioactive substance, and (3) Entry of chlorinated waste which ultimately leads to generation of dioxins and furans.

Mixing of infected waste with non-infected waste leads to increase in volume of infected waste resulting in increase in volume of infected waste. Figure 6.5 shows waste segregation at source. Figure 6.6 shows a chute conveyor in a modern hospital to transfer waste from individual wards in different floors to a centralized

Fig. 6.5 A good practice of onsite segregation. The recycle waste like plastic, sharps and non infected waste shall be segregated to avoid generation of dioxins and furans due to combustion of all the waste and avoid increase in infected waste due to contact between infected and non-infected waste

storage area from where different categories of waste will be collected and transported to a common treatment facility. Failure to segregate infected waste at source may lead to rise in treatment and disposal cost as all the waste needs critical treatment and disposal methods to avoid spread of infection. The entry of mercury, lead and radioactive substances will have direct implication in terms of release of these heavy metals and radioactive substance into air, water, food and soil damaging flora and fauna and physic-chemical components of environment.

Apart from lead and mercury health care units use hazardous chemicals like Cidex, Collodion, Coumadin, Epinephrine, Mitomycin C which are irritant and toxic (Shaner-McRae et al. 2007).

Dioxins and furans are groups of toxic substances that share similar chemical structures. These chemicals are persistent and bioaccumulated. Several dioxins are highly carcinogenic and connected with immune, reproductive, endometriosis, endocrine disturbance and behavioral problems in children (Ryan et al. 2002; Rier and Foster 2002; Schettler 2003). Combustion of biomedical waste which has chlorine in its waste is a major source of dioxines and furans.

All the waste should not be incinerated and the following categories need to be avoided for safety and environmental considerations: (1) large amounts of reactive chemical waste, (2) pressurized gas containers, (3) halogenated plastics, (4) sealed ampoules, (5) waste with heavy metals like mercury, cadmium and lead, (6) silver compounds, and (7) photographic/radiographic wastes.

Even though the dental care activities generate small quantity of waste, some waste is highly toxic in nature (Sreenivasa et al., 2010). Cristina et al. (2009) highlight the need for enhancing dental healthcare service waste management.

Table 6.4 shows a summary of the treatment and disposal options for biomedical waste. Table 6.5 shows the major sources of various categories of waste with in a hospital. The major sources of dental care waste are: (1) department of oral medicine and radiology: major waste generated are syringe, lead foil, biopsy specimens and pharmaceuticals, (2) department conservative density and endodonitcs: major wastes generated in this department are cotton which are soaked in saliva and blood-collected in a container, (3) silver amalgam: amalgam contains

Fig. 6.6 Chute conveyor in modern hospital to transfer waste from individual wards in different floors to centralized storage area from where different category of waste will be collected and transported to common treatment facility

mercury which is toxic and generate immense amount of mercury vapours and waste while handling them, (4) department of peroidontics: major wastes in this department are tissues and scalpels and blades, (5) department of oral and maxillofacial surgery: this department generates extracted teeth, extracted teeth with amalgam, (6) department of prosthodontics: this department generates *plaster of paris*, stone casts, waxes and acrylic resins, (7) department of pedodontics: this department generates extracted teeth (8) department of orthodontics: this department generates orthodontic bands and arch wires-overnight immersion in 2 % glutaraldehyde.

An absence or poor implementation of legislation especially in the developing nations gives rise to concerns about the environmental as well as public health impacts due to poor storage, collection, handling, recycling and disposal of biomedical wastes.

Increase in syringe needle has been dramatic in the past three decades prior to which needles were being reused after heat sterilisation. Occupational transmission of blood borne pathogens has been extremely well documented (Shapiro 1995; Mitsui et al. 1992; Polish et al. 1993; Lanphear et al. 1994; Marcus 1998). Sharps from both human health care as well as veterinary institutes pose health risk to people handling them.

Some service providers in the USA can haul the sharps placed in the pre-paid postage box to the treatment facility of sharps through the US Postal Service. After receipt of sharps confirmation of destruction is made available electronically. Even though such practice is yet to catch up in developing countries it can happen in the near future.

Encapsulation (Fig. 6.7) is one of the methods for the disposal of sharps. In encapsulation sharps are collected in leak proof and puncture-proof containers and

Table 6.5 Checklist depicting major sources of various categories of waste

	Animal Waste	Ash of incinerated biomedical waste	Chemical Waste	Genotoxic	Microbiology and Biotechnology Wastes	Pharmaceutical waste	Pathalogical Waste	Pressurized containers	Radioactive Waste	Sharps	Soiled Waste	Waste With Heavy Metals
Burn unit			✓			✓	✓	✓		✓	✓	✓
Cardiology			✓			✓	✓	✓		✓	✓	✓
Casualty/Emergency/Trauma			✓			✓	✓	✓		✓	✓	✓
Dentistry			✓			✓	✓			✓	✓	✓
Dermatology			✓			✓	✓			✓	✓	✓
Ear Nose Throat (ENT)			✓			✓	✓	✓		✓	✓	✓
Gastroenterology			✓			✓	✓			✓	✓	✓
Incinerator		✓				✓						
Maternity and Gynecology			✓			✓	✓			✓	✓	✓
Neonatology			✓			✓	✓			✓	✓	✓
Nephorology			✓			✓	✓			✓	✓	✓
Oncology			✓	✓		✓	✓			✓	✓	✓
Ophthalmology			✓			✓	✓			✓	✓	✓
Orthopedic			✓			✓	✓			✓	✓	✓
Pathology					✓	✓				✓	✓	
Pediatric			✓			✓	✓			✓	✓	✓
Postmortem						✓				✓	✓	
Pharmacy			✓			✓		✓		✓	✓	✓
Psychiatric						✓						
Pulmonology						✓		✓				
Radiology									✓			
Surgery			✓			✓	✓	✓		✓	✓	✓
Urology			✓			✓	✓			✓	✓	✓
X-ray Department			✓									

when the container is three-quarter full, binding materials like bituminous sand, plastic foam, cement mortar, or clay is poured until the container is completely filled. Medium is then allowed to dry and the containers are sealed and disposed to landfill sites.

Figure 6.8 shows the needle mutilator being used to avoid re-entry of needles into market, but such practice is discouraged in some places considering work place safety.

The risk of infection with HIV after one needle stick exposure is approximately 0.3 % and ranges from 3.3 to 10 % for hepatitis C (Christine et al. 1997).

Figure 6.9 shows sharp pits used for storing needles and other sharps. The pits are provided with small opening from where sharps are dumped into water proof pit with proper lining.

Attempts by health care workers to disassemble sharps waste shall be kept to a minimum. The single uses, self-sealable and locking sharp containers made of plastic are widely used in developed country to protect hospital staff. But the developing countries still continue to discard the sharps in unscientific ways. Law in France has placed the responsibility on the organisations supplying self injection medicines for the disposal of used needles.

Unsafe injections and the subsequent transmission of blood borne pathogens take place regularly in the developing nations. As per the studies conducted by Simonsen et al. (1999) each person in developing nations receives an average of

Fig. 6.7 Needle encapsulation

Fig. 6.8 Needle mutilation under progress

Fig. 6.9 Sharp pits

1.5 injections/person/annum majority of which are not necessary and at least half of the injections in 14 of 19 countries are not safe.

Incineration is not a disposal option for pressurized containers due to the risk of explosion. Undamaged containers like ethylene oxide cartridges or cylinders, nitrous oxide cartridges, cylinders attached to the anaesthesia equipment, pressurized cylinders of oxygen, carbon dioxide, nitrogen, compressed air, hydrogen, cyclopropane, acetylene, petroleum gases, etc., should be returned to the supplier. Damaged pressurized containers which are not suitable for refilling can be crushed after emptied completely, and can be disposed of in landfill.

Sharps can be disposed in a rectangular or circular pit lined with brick/masonry/concrete. The pit should be roofed with heavy concrete slab penetrated by a narrow opening. The pit can be sealed once it is full.

Even though such practice is not observed in many countries, biomedical waste demands special vehicle with proper labelling to indentify from a distance and during accidents. The inside of vehicles should be provided with proper racks to store different categories of waste. The floor shall be metallic and smooth to carry out washing and disinfection activity.

Box 6.1 Path of expired medicine in supply chain

Medicine from manufacturer is delivered to distributors by carrying and forwarding agencies (C&F agencies). The distributors then pass the medicines to wholesale dealers who in turn pass them on to retail chemists. When the medicines expire they are passed on to backwards. The retail chemist will give it to a whole sale dealer who in turn gives it to a distributor and same shall be passed on to C& F agencies. The C& F agencies shall pass the expired drugs to manufacturer for destruction.

If inter-province movement of the expired drugs within a country is restricted by governing laws, the discarded medicine is destroyed within the province where it is generated and certificate of destruction is submitted to manufacturer and enforcing authorities.

In case of hospitals managed by state governments in India, an inventory of medicine is maintained and excess medicine nearing expiry date is passed on to the other hospitals which has shortage of such medicine.

Pharmaceuticals have increasingly been known as chemical pollutants of the environment (Daughton 2003). For proper handling of hazardous pharmaceutical waste, health care establishments need to create additional waste streams (Smith 2007). Pharmaceutical wastes are usually discarded into the trash or dumped into a sink or toilet and enter the sewer waste stream (Smith 2002) even though bulk of it is disposed by manufacturer/distributors (**Box 6.1**). Most sewage and water treatment facilities do not consider pharmaceutical contaminants; hence these wastes are left untreated and enter surface, ground, and drinking water (Kummerer 2001).

Fig. 6.10 Expired medicines being segregated from packaging prior to incineration

Figure 6.10 shows common disposal facility wherein pharmaceuticals are separated from their packaging materials. The metal/glass/plastic packing is usually separated to avoid load on disposal facilities. Pharmaceuticals need to be scientifically disposed of by high temperature (i.e. above 1,200 °C) incineration. Pharmaceuticals need particular attention during disasters as large quantities of pharmaceuticals are donated as humanitarian assistance demanding safe disposal if this assistance is unused.

Segregation

Segregation is the most important procedure in biomedical waste handling. In addition to segregation at source discussed earlier health care establishments also have to provide good transfer point before hauling to treatment/disposal facility. Figure 6.11 shows individual rooms with colour coding so that the different category will not be mixed with each other.

Incineration is one of the economical ways of destructing pathogens. Figure 6.12 shows batch type double chambered incinerator. The rotary incinerators are available in the range of 0.5–3 tons/hour and hence are appropriate if the quantity to be treated is high. But it is appropriate to make feasibility study before finalizing the incinerator.

Batch type biomedical incinerator shall have two chambers and shall have at least 99.00 % combustion efficiency (C.E).

The combustion efficiency is calculated using equation:

$$\text{Combustion efficiency} = (\%CO_2)(100)/(\%\ CO_2 + \%\ CO)$$

When biomedical wastes are loaded with halogenated chemicals, dioxins/furans and other toxic air pollutants may be generated. The gases generated in primary chamber are heated to high temperatures to destroy gaseous organic compounds.

The temperature at primary chamber shall be 800 ± 50 °C from where gases entre secondary chamber maintained at 1,050 ± 50 °C where gas residence time should be at least one second, with at least 3 % oxygen in the stack emission.

Fig. 6.11 Individual rooms with colour coding as per local legislation or protocol will increase chances of cross contamination and reduce cost of treatment and disposal incineration

Fig. 6.12 Biomedical waste incinerator

Further efficient segregation of plastics at source to eliminate PVC will also help in tackling generation of dioxins and furans.

Rotary kiln operates at 1,200–1,600 °C allowing decomposition of persistent chemicals such as PCBs. The rotary kilns have a slope of 3–5 % and rotate 2–5 turns per minute. The waste is inserted at the top and ashes are emptied at the bottom of the kiln. Gases from primary chamber are heated to elevated temperatures to destroy gaseous organic compounds and usually have a residence time of two seconds. Biomedical waste incineration is one of the main sources of dioxin and furan (Lerner 1997; Walker and Cooper 1992; Vesilind et al. 2002).

Incineration is an option to dispose of pharmaceutical waste but low-temperature incineration (<800 °C) provides only limited treatment. Hence a dual chambered incinerator discussed above is used. Parmaceuticals are treated in incinerators which operate at high temperatures (>1,200 °C). In many nations cement kilns are also used for disposal of treatment of pharmaceutical waste.

Fig. 6.13 Autoclave

Autoclaving

The autoclave should be dedicated for treating biomedical waste. Figure 6.13 shows biomedical waste autoclave. The biomedical waste should be subjected to (1) a temperature of more than 121 °C and pressure of 15 pounds per square inch (psi) for a residence time of more than 60 min, or (2) a temperature of more than 135 °C and a pressure of 31 psi for a residence time of more than 45 min, or (3) a temperature of not less than 149 °C and a pressure of 52 psi for a residence time of more than half an hour.

While operating a vacuum autoclave, biomedical waste should be subjected to a minimum of one pre-vacuum pulse to eliminate the air from autoclave.

Biomedical waste shall be considered properly treated only when the time, temperature and pressure indicators indicate required temperature, pressure and time were reached during the autoclave process. If for any reasons, temperature, pressure or time indicator indicates that the required values was not reached, the entire biomedical waste must be autoclaved again till the proper temperature, pressure or time are achieved.

The autoclave should be completely and constantly kill biological indicator at the maximum design capacity. Common biological indicator for autoclave is bacillus stearothermophilus spores. Vials or spore strips of indicators with at least 1×10^4 spores per millilitre are used for testing. Autoclave used for treating biomedical waste shall have a residence time of more 30 min, regardless of temperature and pressure, a temperature more 121 °C or a pressure more 15 psi.

A chemical indicator tape/strip that changes colour when a temperature is reached can be used to confirm that a specific temperature is achieved. It is prudent to use more than one strip over the waste package at various locations to make sure that the entire package is adequately autoclaved.

Shredding

Shredding is carried out to avoid re-entry of contaminated plastic and glass items to market. Figure 6.14 shows shredding process under progress. The shredded plastic and glass can then be reprocessed for manufacture of new items.

Fig. 6.14 Biomedical waste being fed into the shredder

Hybrid treatments

These are the treatment units in where two or more treatment processes are carried out simultaneously. Typical examples include hydro clave wherein shredding and autoclaving is carried out simultaneously. Another example includes microwaving and autoclaving being carried out in single equipment.

Rotating-blade shredders are most widely are used in shredding biomedical waste. They consist of blades attached to wheels rotating in opposite directions.

Microwaving

Microwave treatment should not be used for cytotoxic, hazardous or radioactive wastes, contaminated animal carcasses, body parts and large metal items. Presence of metal leads to sparkling and possibly health hazards. The microwaving demands comparatively higher investment and proper segregation of waste.

Deep Burial

Deep burial pits are recommended and used in rural and isolated areas where it is not prudent to invest huge amount of money. Figure 6.15 shows a typical deep burial facility. A deep burial pit/trench is dug approximately two metres deep. The biomedical waste shall be half filled and covered with lime followed by soil. This method needs adequate precaution so that animals do not have access to burial sites. Proper covers of sheet metal or wire meshes may be used. When wastes are inserted to the pit, a layer of approximately 10 cm of soil should be spread to cover the wastes. The deep burial site should be relatively impermeable. No shallow well shall be close to the deep burial pit. The pits should be away from habitation, and sited in such a way that no surface water or groundwater contamination occurs. The deep burial location shall not be prone to erosion or flooding.

H5N1 strain of avian flu originated from China in 1996 spread rapidly across Asia, Europe, and Africa. The presence of was confirmed in birds/humans in more than 55 countries (Ganesh et al. 2008). The main means of transmission to humans was through contact with infected live poultry and surfaces contaminated with

Fig. 6.15 Biomedical waste deep burial facility

secretions/excretions of infected birds. Avian flu outbreak during 2003 and 2004 resulted in the death/destruction of 44 million Birds and 29 million birds, in Vietnam and Thailand respectively. As of mid-2006, about 200 million domestic birds had either died or culled (FAO 2012).

About 24 tonnes of poultry feed, about 28 thousand eggs, and more than 3 lakh birds were destroyed after 2007 avian flu outbreak in Manipur district of India along with contaminated material from 166 farms in the infected zone (Ganesh et al. 2008).

Birds during out break were usually killed by decapitation (Cutting head) or by feeding poisons. Some farms used sedatives mixed with water prior to culling operation. The culled bird were packed in bas and disposed within farm premises. During the past outbreaks of avian flu announcement were made in some countries asking owners of backyard poultry birds not to release the birds in the morning so that veterans could collect birds in the next morning making cash payment.

As per, the infected birds can be disposed off by open fire or deep burial. Even though it is well known fact that uncontrolled combustion would lead to air emissions, creating such infrastructure during epidemics is not possible within few days/hours. The wood requirement will be around 500 kg per 100 kg of dead birds. Deep burial with a dimension of $2 \times 2 \times 2$ m would accommodate 1,800 dead birds. It is necessary to ensure the groundwater levels to avoid groundwater contamination.

Apart from infected birds, infected material in poultry like meat, eggs, egg trays, used litter, manure, feather, feed, feed ingredients, and manure, cloths used by farm personnel, drugs and vaccines should also be destroyed by deep burial or open burning. While it is recommended that crops grown in the farm should be uprooted and buried/burnt, it is not practiced by farmers as they cannot afford financial shock.

DAHDR (Department of Animal Husbandry, Dairying and Fisheries), Ministry of Agriculture, Government of India, 2006: Action Plan of Animal Husbandry for Preparedness, Control and Containment of Avian Influenza.

Fig. 6.16 Biomedical waste being chemically treated

Chemical Treatment

Chemical treatment can be both on- and off site. While it is recommended to use disinfectant a point of generation with respect to sharps, other wastes can be disinfected as shown in Fig. 6.16. Chemical treatment is the choice where power is not available to operate autoclave or any other equipment which demands power. Chemicals are added to the waste to kill or inactivate the pathogens in biomedical waste. The choice of chemical depends on the availability of chemical and safety of the operator. It is essential that large biomedical waste and waste with cavity be shredded for better efficiency. Table 6.6 shows commonly used chemical disinfectants in which can be used for disinfection of biomedical waste. 1 % (of active chlorine) sodium hypochlorite is most commonly used disinfectant due to safety reason but care should be taken to treat the waste while active chlorine is still present as chemical is not stable.

Needle Encapsulation

Needles are often source of infection spreading and hence need extra care for avoiding re-entry into user stream.

6.5 Radioactive Waste

Management of radioactive waste from health care establishments should follow appropriate national legislation. The waste may be suitable for release after some days to a few years. If a release is not permitted as per law, waste should be returned to the supplier/producer of the original material.

Waste that can neither be returned nor released to the supplier/producer, waste should be destined to a disposal facility or a facility for long term storage for future disposal after treatment or conditioning of waste.

Containers of radioactive waste should be marked as ‘RADIOACTIVE WASTE’ with the radiation symbol. The container should be labeled with

Table 6.6 Commonly used chemical disinfectants which can be used for disinfection of solid wastes

Chemical	Application	Physical and chemical properties	Health hazards
Chlorine dioxide	Active against most bacteria, viruses, and spores	Reddish-yellow gas at ambient temperature reacts with water/steam to generate corrosive fumes of hydrochloric acid; explosion limit: >10 % in air	Irritant to skin, eyes, and respiratory tract; toxic
Sodium hypochlorite	Active against most viruses, bacteria, and spores; not effective for disinfection of liquids with high organic content like blood or stools	Available as aqueous solution with 2–12 % of active chlorine; solutions of low concentration are more stable; decomposes at ambient temperature into sodium chloride, sodium chlorate and oxygen; reacts with acids to generate hazardous chlorine gas; light will accelerate decomposition	Irritant to eyes, skin, and respiratory tract; toxic
Glutaraldehyde	Active against both bacteria and parasite eggs	Available in 25–50 % aqueous solutions; shall be used with acetate buffer as 2 % aqueous solution	Concentrated solutions are irritant to skin and eyes
Ethylene oxide	Inactivating effect against all micro-organisms	Flammable and explosive above 10 °C at concentrations of 3 % and above in mixtures with air; soluble in water and many organic solvents; very reactive at ambient temperature	Extremely irritant to skin and eyes; classified as a human carcinogen
Formaldehyde	Inactivating effect against all micro-organisms; can be used for dry, solid waste, in combination with steam at 80 °C. Contact time: 45 min	Gas at ambient temperature; polymerizes at temperatures below 80 °C; flammable and explosive at concentrations of 7–73 % in mixtures with air; reactive at ambient temperature. Formalin is a 37 % solution of formaldehyde	Irritant to skin, eyes, and respiratory tract; toxic. Formaldehyde is classified as a probable human carcinogen

information required by statute such as origin of the waste, period of storage required, quantity, responsible person, etc.

Storage facilities for radioactive waste shall have the following the characteristics:

- Shall have adequate capacity to store waste generated prior to treatment, or transportation,
- Shall have non-flammable walls and floors,
- Shall have simple construction,
- Floor shall be impermeable and constructed in a way that it can be easily decontaminated,
- Shall be fire-resistant and have lockable doors,
- Shall have adequate ventilation,
- Shall have arrangement for air sampling and radiation alarms,
- Shall have fire control/detection equipment as required by per statute,
- Shall have compartments to store different kinds of waste,
- Shall have demarcation as required by regulatory authority,
- Shall have a record keeping mechanism about all the information required as per statute,
- Shall provide protection to waste from weather, and
- Shall have movable radiation shielding to protect workers from radiation.

Treatment and conditioning

Treatment is carried out to enhance the characteristics of waste before storage/disposal. The basic objectives of the treatment are:

Volume reduction (for liquid waste: evaporation under controlled conditions, for solid waste: low-force compaction, shredding, and controlled incineration).

Removal of radionuclides (for liquid waste: ion exchange, for solid waste: decontamination).

Change of composition (for solid waste: not applicable, for liquid waste: precipitation/filtration).

Treatment processes can result in the generation of secondary radioactive wastes (spent resins, contaminated filters, sludge, ash) and they should be managed appropriately.

Conditioning is used for converting radioactive waste to a form which is more suitable for handling. The operations include (1) placing the waste in suitable containers, (2) immobilization of radioactive waste in concrete, (3) and providing additional packaging.

Precautions for handling radioactive waste

1. Disposal of sharps containing radioactive residues shall be carried out after storing the same until radiation reaches permissible limits,
2. Radioactive solid waste should not be treated by autoclave or microwave,
3. Solid radioactive waste like bottles, glassware, and containers shall be deformed/mutilated before disposal to avoid reuse,
4. Radioactive waste of shall be stored for decay in labelled containers, under lead shielding, until radiation reaches permissible limits,

5. Spilled radioactive waste shall be retained in suitable containers until the radiation reaches permissible limits, and
6. Patient's excreta after diagnostic procedures shall be checked frequently for radioactive contamination.

6.6 Mercury in Biomedical Waste

Health care facilities contain an array of mercury-containing products, e.g., medical instruments, clinical laboratory chemicals (fixatives, stains, reagents, preservatives, dental amalgam, electrical equipment, mercury cells (batteries), fluorescent lamps and cleaning solutions.

Mercury based instruments used in health care facilities include:

1. Thermometers (used for measurement of body temperatures),
2. Sphygmomanometers (used for measurement of blood pressure),
3. Esophageal dilators (bougie tubes),
4. Feeding tubes,
5. Miller Abbott tubes and Cantor tubes (used to clear intestinal obstructions),
6. Gastrointestinal tubes,
7. Intraocular pressure devices,
8. Strain gauge,
9. Urinometer,
10. X-Ray Machines, and
11. Barometers in respiratory therapy.

Breakage of the above instruments can results in a potentially hazardous spillage affecting humans and environment.

Strategies for management of mercury containing waste in health care facility include:

1. Separation of reusable and non-reusable mercury containing products,
2. Recycling mercury-containing goods,
3. Proper handling/disposal of mercury and mercury contaminated waste, and
4. Using alternatives for products that contain mercury.

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Chapter 7
Hazardous Waste

Industrial revolution has resulted in a grave problem of generation of hazardous waste in large quantities. Outdated technology, knowledge gap, weak enforcing, corruption and waste trafficking are a few of the barriers for effective hazardous waste management systems in many nations. The size and type of industries vary from country to country and so do the volume and qualities of waste.

As per the Hazardous Wastes (Management and Handling) Rules, 1989 (as amended, May, 2003) of India:

> "hazardous waste" means any waste which by reason of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes danger or is likely to cause danger to health or environment, whether alone or when in contact with other wastes or substances, and shall include-
>
> (a) wastes listed in column (3) of Schedule-1;
> (b) wastes having constituents listed in Schedule-2 of their concentration is equal to or more than the limit indicated in the said Schedule; and
> (c) wastes listed in Lists 'A' and 'B' of Schedule-3 (Part-A) applicable only in case(s) of import or export of hazardous wastes in accordance with rules 12, 13 and 14 if they possess any of the hazardous characteristics listed in Part-B of Schedule-3.

As per the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008 which supersede the Hazardous Wastes (Management and Handling) Rules, 1989

> "Hazardous Waste" means any waste which by reason of any of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics causes damage or is likely to cause danger or is likely to cause danger to health or environment, whether alone or when in contact with other wastes or substances, and shall include
>
> (i) Waste specified in column (3) of Schedule-I;
> (ii) Wastes having constituents specified in Schedule II if their concentration is equal to or more than the limit indicated in the said Schedule; and

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Fig. 7.1 Soil contamination due to hazardous waste disposal

(iii) Wastes specified in Part A or Part B of the Schedule III in respect of import or export of such wastes in accordance with rules 12, 13 and 14 or the wastes other than those specified in Part A or Part B if they possess any of the hazardous characteristics specified in Part C of that Schedule.

With the slight modification in definition and the list of waste in the rules the quantity of waste quantification would take new dimension.

As per Waste Management Regulation, 2006, of Kenya:

> waste considered as hazardous, shall be any waste specified in the Fourth Schedule or any waste having the characteristics defined in the Fifth Schedule, and any wastes which do not fit the said categories of classification will be treated as non-hazardous waste.

Infectious substances are addressed in separate rules in India. Whereas 'substances or wastes containing viable micro-organisms or their toxins which are known or suspected to cause disease in animals or humans' is one of characteristics that qualifies waste to be hazardous in Kenya.

Hazardous waste has drawn its significance from the fact that it can damage both health and environment even in small quantity. While degradable matters like vegetable and leaves decay over period of time hazardous waste will have its impact (Fig. 7.1) intact over centuries if not remediated.

7.1 Significance

Hazardous wastes have the potential, even in low concentrations, to have a significant adverse effect on the environment and public health due to its inherent toxicological, physical and chemical characteristics (DWAF 1998). Many hazardous waste generating industries have shifted to the developing countries due to the associated low management cost and nonstringent regulations. On the other hand the developing countries hug the opportunity as an opportunity for investment and learn new technology. The end result is the generation of hazardous waste which is often mis-handled leading to adverse impact on environment.

The quantity of hazardous waste generated in industries is often wrongly reported to avoid statutory obligation. The hazardous waste is often tipped off in virgin environment including forest and sensitive water bodies. The coastal area has advantage to tip off the waste during the night. The waste may be pumped into underground or spread on the ground and covered with a layer of soil. Some time, the waste is set fire and reported as *fire accident* by waste handlers cutting the waste treatment and disposal costs.

7.2 Precautions to be Taken Storage and Transportation of Hazardous Waste

Hazardous waste transport involves *multiple players* which include shippers, carriers, manufacturers, distributors, freight forwarders, emergency responders, government regulators etc. Further *hazardous materials* demand proper tracking and safety precautions. Considering all these constraints principles for hazardous materials transportation can be laid down as: (1) commitment towards the risk reduction, (2) promote risk reduction culture, (3) interaction with those involved in hazardous materials transport chain, (4) communicate risk reduction priorities, (5) act to reduce risk, (6) improve efficiency continuously, and (7) share knowledge about risk.

Unlike MSW, hazardous waste transportation is a new issue and challenge in the developing world and as such countries require to gear up for the following: (1) community awareness, (2) formulation and enforcing new set of regulation, (3) lay down monitoring mechanism, (4) creating a new data base, (5) develop emergency medical response system, (6) training police, officials at check posts, and custom officers.

In countries wherein there are no proper transportation mechanisms, it is difficult to ensure transportation of hazardous waste. The community and transporter also need to develop their own strategy as the traffic and road conditions will be totally different form that of another country.

Proper transportation should have: (1) safe vehicles, (2) trained personnel/ regulators, (3) good tracking system, (4) emergency management plan, and (5) system to respond to emergencies.

Each personnel involved in the transportation of hazardous waste (like packaging, preparing the shipping paper or labelling the drum) must have training with respect to applicable law and methodology. But in reality it may not happen as organizations are under staffed to cut the expenditure. In many countries regulating agencies themselves lack the knowledge.

All hazardous waste must be correctly identified. For example, a waste shipping paper shall have the following documents: (1) shipper's name and address, (2) consignee's name and address, (3) details of destination, (4) basic description of waste, (5) details of weight and volume, (6) type and kind of package, (7) emergency response information, (8) emergency response contact number, (9) information on immediate health hazards, fire or explosion, (10) immediate precautions to be taken during accident/incident, (11) preliminary first aid measures, and (12) methods for handling spills or leaks. All these information are usually incorporated in mandatory forms stipulated in legislation.

The above information can supplemented with an MSDS and Emergency Response guidebook. But practically such information does not serve purpose if the driver is illiterate, which is case in many developing countries. Hiring a literate driver some time may not be possible due to low alary associated with the job. In a nutshell such complexity leads to increase in hauling costs and would place greater burden on the waste generators.

7.3 Characteristics and Quantity

As the countries shift from labour intensive industries to machine based manufacturing industries, the waste quality and quantities would also vary. Almost all the countries have legislations with respect to hazardous waste due to international pressure arising from treaties and conventions. However, the definitions they adopt are not uniform all over the world.

Usual practice with respect to disposal of hazardous waste is through a treatment storage disposal facility (TSDF) where a waste generator will make agreement to hand over the waste. The TSDF operator will collect the master samples of different type of waste and analyse the same. Table 7.1 gives some example of waste analysis parameters. It is a usual practice to keep a master sample which is representative of the industry in TSDF facility for nearly period of 5 years as shown in Fig. 7.2.

The quantity of hazardous waste generated in different countries depends on the major industrial activities in the country. As per (Cirillo et al. 1994) 30 % of hazardous waste is produced from electroplating and metal industries in Malaysia, whereas in Thailand the principal hazardous waste is generated from manufacturing (33 %) and metal smelting (47 %) industries.

South Africa generated about 538 million tonnes of waste in the year 1997 with the sewage sludge contributing 0.1 %, domestic and trade 1.5 %, industrial 3.1 %, agriculture and forestry 3.8 %, power generation 3.9 % and mining for 87.7 %, (DWAF 1998). Figure 7.3 shows the hazardous waste quantities in some of the Southeast Asian countries (Cirillo et al. 1994; Hay et al. 1994).

New forms of waste referred as 'nanowastes' contain engineered nanomaterials, nanoparticles or synthetic by-products of a nanoscale, either from production/ storage/distribution, or consequential from the end of lifespan of

Table 7.1 Examples of waste analysis parameters

Sl. No.	Rationale for selection	Waste parameter(s)
1	To identify (1) material to make waste container, (2) storage conditions, applicable regulation, (3) health and safety precautions.	pH, total and amenable cyanide/sulphide, Flash Point, Other Appropriate constituent(s)
2	To identify (1) material to make tanks/ancillary equipment, (2) applicable regulation, (3) applicable requirements to treat and dispose waste, (4) corrosion management, (5) health/safety precautions.	pH, flash point, oxidizing potential, halogens, total and amenable Cyanide/Sulphide, appropriate hazardous constituent(s)
3	To identify (1) wastes that may need pre-treatment to ensure optimum effectiveness, (2) relevant health/safety considerations, (3) effects from electrical conductivity, (4) applicable regulations.	pH, total metals, electrical conductivity, total and amenable cyanide/ sulphide, appropriate hazardous constituent(s)
4	To identify (1) the presence/absence of free liquids, (2) material that affect landfill liners, (3) relevant health/safety precautions, (4) applicable regulations.	Free liquid content, pH, total chlorine, total nitrogen, liner compatibility, chemical compatibility, evaluations, total and amenable Cyanide/ Sulphide, appropriate hazardous constituent(s)
5	To identify (1) wastes that may inhibit combustion or require mixing with high-calorific wastes, (2) moisture content, (3) possible air pollutants, (4) acceptance limits for chlorine content, (5) corrosively, (6) affect incinerator performance, (7) applicable regulation, (8) relevant health/ safety precautions	Heat content, percent moisture, chlorine content, ash content, pH, viscosity, total metals, appropriate hazardous constituent(s)
6	To identify (1) wastes that may inhibit combustion or require mixing with high-calorific wastes, (2) moisture content, possible air pollutants, (3) acceptance limits for chlorine content, (4) corrosively, (5) affect incinerator performance, (6) applicable regulation, (7) wastes that may corrode system components, (8) wastes that may not be agreeable to normal conveyance systems, (9)wastes that are prohibited from management in BIFs, (10) wastes that may affect BIF performance, (11) applicable regulation, (12) relevant health/safety precautions	pH, viscosity, calorific value, ash content, total metals, chlorine content, appropriate hazardous constituent(s)

Fig. 7.2 Master samples preserved at a TSDF site

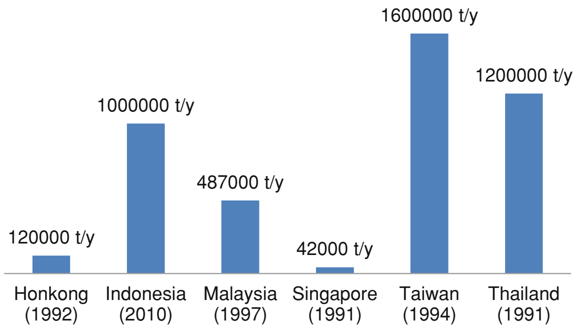


Fig. 7.3 Hazardous waste quantity in some of the Southeast Asian countries

nanotechnologically enabled products and materials. Since the global statistics of nanomaterials and nanoparticles are incomplete, nanowastes generated each year are also unknown.

Figure 7.4 gives the records and manifestations used at different stages of transportation. Records of the quantity of hazardous waste need to be carried out to ensure proper tracking.

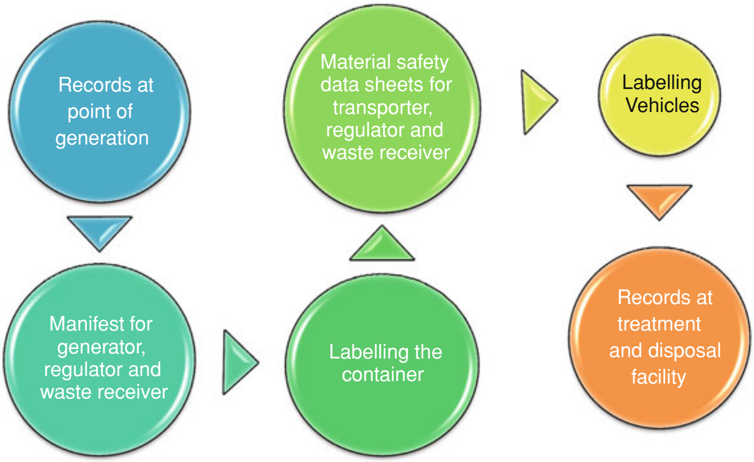
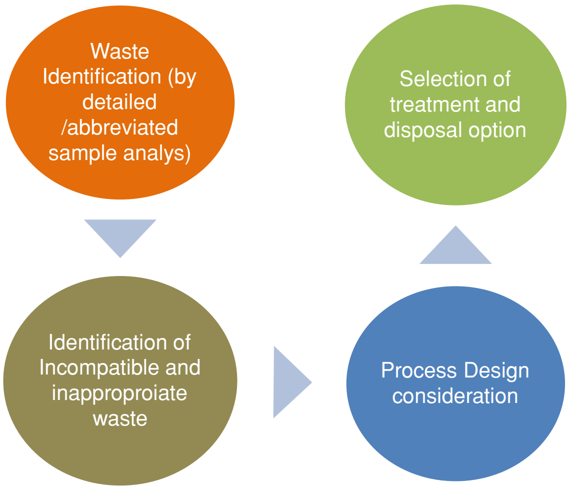


Fig. 7.4 Records and manifest used at different stages of transportation

Fig. 7.5 Correlation of waste analysis with treatment and disposal option



Once the sample is collected preservation techniques must be employed to ensure the integrity of the waste remains intact. Sample preservation may not be required for highly concentrated samples. But low concentration samples require preservation. Sample preservation techniques include: (1) preserving with appropriate chemicals (like sodium thiosulfate to reduce organochlorine reactions, acid to liquids containing metals, adding acid to suppress biological activity), (2) refrigerating samples, and (3) storing and shipping samples in suitable container.

Abbreviated waste analysis, frequently referred to as "fingerprint analysis", is conducted usually for specific gravity, color, flash point, presence of more than one phase, pH, halogen content, cyanide content, percent water that will provide

Fig. 7.6 Used crackers which comprise of many toxic chemicals

information to verify that the waste received matches the expected characteristics. If there is deviation in analysis results of waste received form waste characteristics of master sample then there would be need for detailed analysis. The analysis results are used to decide mode of treatment and disposal. Figure 7.5 shows correlation of waste analysis with treatment and disposal system.

7.3.1 Household Hazardous Waste and Special Waste

Household hazardous waste (HHW) is a subgroup of hazardous waste commonly found in MSW and in wastewater streams. These special wastes originate in households. HHW pose problems in safe handling. They pose human health and environmental hazards.

Examples of HHW include expired drugs, adhesives, glues, cements, roof coatings, sealants, epoxy resins, solvent based paints, solvents and thinners, painter removers, strippers, oven cleaners, degreasers and spot removers, toilet cleaners, polishes, waxes, and strippers, chimney cleaners, solvent cleaning fluids, insecticides, fungicides, rodenticides, molluscides, wood preservatives, moss retardants and chemical removers, herbicides, fertilizers, batteries, paints, solvents, cleaners, additives, gasoline, flushes, auto repair materials, motor oil, diesel fuel, antifreeze, photo chemicals, pool chemicals, glues, inks, dyes, glazes, chemistry sets, pressurized gas containers, white gas, charcoal lighter fluid, household batteries, ammunition, asbestos, fireworks, lamps, Freon recovered from white goods, and electronics, including computer components, televisions, and other electronic equipments. Figure 7.6 shows used crackers which comprise of many toxic chemicals.

Many of these waste materials are categorized as hazardous because they will have any of the following properties: (1) ignitability with flash point less than 140°F, (2) corrosivity, (3) reactivity with water and other materials, and (4) toxicity to animals and human beings.

The quantities of HHW vary from country to country and house to house. The quantities have been estimated to vary between 0.01 and 3.4 % of MSW by weight (David and Rachel 2002). The variability depends on the development of a country and income of individual. HHW represents the most toxic part of the waste stream. Household hazardous products (HHPs) influence the risks to health and environment during their use and disposal. Chemicals in HHP can affect health through ingestion, inhalation, or absorption. Some HHPs emit toxic fumes which will cause headaches, fatigue, eye irritation, runny noses, and skin rashes. Children and aged people are at a much higher risk compared to others.

Storm water runoff is a leading cause of environmental pollution due to HHP. Chemicals, pesticides and fertilizers used in household will be carried away by rainwater causing surface and groundwater pollution.

Use of HHP like fuels, crackers, combustible substance with low ignitions point has resulted in fire risks all over the world many of which will go unreported. Toxic compounds that are heated during combustion will release in the fire.

HHW in MSW would result in release of toxicity into air and water at dumpsites, land fill sites and incineration plants. HHW may be diverted from MSW as done in Clark County, Washington (David and Rachel 2002).

Special waste is defined differently in different countries, legislations and literature. As per Howard et al. (1986), special waste includes items like street sweepings, abandoned vehicle, dead animals etc. As per Resource Conservation and Recovery Act of the USA enacted in 1976, special waste include: (1) mining waste, (2) oil and gas drilling muds and oil production brines, (3) phosphate rock mining, beneficiation, and processing waste, (4) uranium waste, (5) utility waste (i.e., fossil fuel combustion waste) (USEPA NA 2012).

The Special Waste Regulations 1996 of the UK, special waste is clearly listed in schedule II of the regulations excluded household waste from the definition of special waste.

Special or unusual waste may include items like sludge from, wastewater treatment facilities, tires, and dead animals. These special wastes should be managed in a way to protect human health and environment.

7.3.2 Hazardous Waste From Rural and Urban Area

It is often understood that the industries and urban areas are the origins of hazardous wastes. Irrespective of whether a country is underdeveloped or developed rural areas do contribute the waste which is diluted within in the rural area. Even though the impact is not visible immediately, it would harm the health and environment over period of time. The common hazardous substance used in rural area includes insecticide, pesticide, fungicide, herbicide, chemical fertilisers, chemicals used for fumigation, cleaning agents used in animal husbandry. Further, the use of household hazardous chemicals discussed earlier are also become part of hazardous waste from rural area. The packaging materials are either thrown

Fig. 7.7 Onsite storage of hazardous waste at an industry

haphazardly or reused after washing sufficiently. The impact of such practice will occur over long period leading to decline in earth worms and useful insects, change in soil characteristic, sickness in consumers (humans and animals) which include cancer, water pollution. Quantities are often not estimated and reported. In addition to agricultural activity the presence of mining, quarrying, small scale industry, motels, and garages would also contribute substantial hazardous waste. The fly-tipping of waste from urban area and illegal burying would have impact in the course of long time.

7.4 Storage of Hazardous Waste

Hazardous waste is stored at the points of generation and disposal. Storage at site shall be done considering the climate and safety precautions. Storage in open area as shown in Fig. 7.7 should not be done. Storage yard of hazardous waste should be kept away from storage yard of raw materials and finished products. A dedicated storage yard (Fig. 7.8) with proper ventilation, fire fighting system (Fig. 7.9) shall be provided with access to only trained authorised personnel. The storage containers should be properly labelled (Fig. 7.10) and care should be taken to ensure waste is compatible with material of container.

Storage area or sheds shall confirm the following precautionary measures to avoid hazards: (1) non-compatible wastes must be stored separately preferably in separate shed, (2) storage shed shall adequate openings in order escape during hazards, (3) the storage shall have adequate storage capacity preferably 50 % of the annual capacity, (4) storage area should be capable of withstanding the load of material stocked, (5) construction material shall be capable of resisting the spillages, (6) storage area shall be provided with the flameproof electrical fittings, (7) sheds should be provided with automatic smoke, heat detection system, (8) the

Fig. 7.8 Onsite storage of hazardous waste with a closed structure

Fig. 7.9 Stacking and sprinkler arrangement at a waste disposal facility

Fig. 7.10 Labelling of hazardous waste

storage are shall have adequate fire fighting systems, (9) two storage sheds shall be constructed at least 15 m apart, (10) operation shall be done by trained staff, (11) at least 4 m distance shall be maintained between two blocks of stacked drums to avoid spreading of fire in case of fire hazard, (12) precaution shall be taken to store maximum 300 MT in each block, (13) minimum of ome meter clear space shall be maintained between two adjoining rows of drums in pair, (14) the storage shed shall have at least two routes to escape during fire accidents, (15) storage area should have doors and approaches with suitable sizes for movement of fork lift and firefighting equipment, (16) the exhaust of vehicles in hazardous waste storage area shall be fitted with spark arrester, (17) measures should be taken to avoid entry of rainwater and runoff in the storage area, (18) floor of the storage area shall be at least 150 mm higher than the maximum flood level, (19) the storage area floor shall be provided with secondary containment, (20) storage areas shall have proper peripheral drainage system with the sump to collect accidental spills.

The container used for storage of hazardous waste shall be compatible with the hazardous wastes planned to be stored and stacking of drums should be restricted to three (except the waste with flash point less than 65.5°C). The container shall be stored on wooden frames and necessary measures should be taken to avoid stack collapse. Drums should be opened in designated places for sampling or otherwise outside the storage areas.

7.5 Treatment and Disposal

Treatment and disposal can occur at point of generation or offsite. In many countries TSDF sites are not established. In such countries the disposal is carried out onsite at the locations where hazardous waste is generated.

Depending on whether the hazardous substance is gas/liquid/solid the following methods are employed for hazardous waste treatment.

1. Physical treatment processes

   a. Gas cleaning

i. Mechanical collection
ii. Electrostatic precipitation
iii. Fabric filter
iv. Wet scrubbing
v. Dry scrubbing
vi. Adsorption

   b. Liquids-solids separation

i. Centrifugation
ii. Coagulation
iii. Filtration

iv. Flocculation
v. Flotation
vi. Foaming
vii. Sedimentation
viii. Thickening

c. Removal of specific component

i. Adsorption
ii. Crystallization
iii. Dialysis
iv. Distillation
v. Electro dialysis
vi. Evaporation
vii. Leaching
viii. Reverse osmosis
ix. Microfiltration
x. Solvent extraction
xi. Stripping

2. Chemical treatment processes

   a. Absorption
   b. Chemical oxidation
   c. Chemical precipitation
   d. Chemical reduction
   e. Oxidation
   f. Ion exchange
   g. Neutralization
   h. Chemical fixation and solidification
   i. Dehalogenation

3. Biological treatment processes

   a. Aerobic systems
   b. Anaerobic systems
   c. Activated sludge process
   d. Rotating biological contactors
   e. Sequential batch reactor
   f. Spray irrigation
   g. Tricking filters
   h. Waste stabilization ponds

Treatment of gases/liquids often results in solids which need further treatment and ultimate disposal.

Fig. 7.11 Vehicle mounted mixer at a TSDF facility for mixing stabilisers

7.5.1 Stabilization and Solidification

Stabilization and solidification of hazardous waste have been widely used as pretreatment before landfills. Stabilization is a process of mixing additives to waste to minimize the rate of migration of contaminant to environment. Solidification is a technique of encapsulating the waste, to form a solid material. Fixation is often used as synonym for stabilization. Figure 7.11 shows vehicle mounted mixer at a TSDF facility for mixing stabilisers. Figure 7.12 shows mixing platform at a TSDF site. Figure 7.13 shows improper disposal without stabilization and solidification.

Successful stabilization involves any of the following mechanisms or combination of these mechanisms: (1) absorption, (2) adsorption, (3) detoxification, (4) macro encapsulation, (5) microencapsulation, and (6) precipitation.

Absorption is a process wherein contaminants are taken into sorbent and are electrochemically bonded to stabilizing agents. Detoxification is a process wherein toxicity of a substance is reduced. Macro encapsulation is mechanism wherein constituents of hazardous waste are physically entrapped in larger structural matrix. Microencapsulation is mechanism wherein constituents of hazardous waste are entrapped in the crystalline structure of solidified matrix.

Precipitation is the formation of a solution or another solid during a chemical reaction or diffusion. The following paragraphs discuss some of the stabilizing and solidifying agents which are widely used. Some proprietary mixtures available in the market can also be used after testing their properties.

Cement

Hydration of cement forms crystalline structure resulting in rock like hardened mass and is best suited for inorganic waste. Due to high pH of cement, the metals are retained in the form of insoluble carbonate or hydroxide.

Lime

Lime is a general term for the different forms of calcium oxide/hydroxide and smaller amounts of magnesium oxide/hydroxide. Waste and soil stabilization using

Fig. 7.12 Mixing platforms at a TSDF site

lime is widely established (Sherwood 1993; Chaddock and Atkinson 1997; Aggregate Advisory Service 1999). Lime forms hydrates of calcium silicate, calcium alumina, or calcium alumino-silicate depending on the constituents of hazardous waste and hence typically best suited for inorganic contaminants. Lime can also be added to acidic waste along with other stabilizing agents.

Organically Modified Clay

Organically modified clay is achieved by replacement of inorganic cations of the clay by organic cations. Such clay will adsorb organic molecule within the crystalline structure of clay.

Thermoplastic materials

Thermoplastic include bitumen and sulfur polymer cement (Lin et al. 1995, 1996). Bitumen may be used on their own or in combination with cement (British Cement Association 2001).

Thermosetting Organic Polymers

Thermosetting polymer is mixed with hazardous waste in the presence of monomer such as urea–formaldehyde that acts as a catalyst.

Pozzolanic Materal

Pozzolan is a material that exhibits cementitious properties when combined with calcium hydroxide. Pozzolanic materials include cement kiln dust, ground blast furnace slag, and fly ash. Natural pozzolanic materials are mainly volcanic in origin, and have cementations properties. Some natural pozzolans which are non-cementitious may become pozzolanic when heated (Taylor 1997).

Secondary Stabilizing Agents

These are materials that are not effective on their own but can be used in combination with lime or cement. The secondary stabilizing agents include pozzolans which can react with lime and water to produce cemetitious material.

Silica-fume which is a by-product of smelting process for silicon metal and ferrosilicon alloy production has an amorphous structure and a high SiO_2 content, coupled with a large surface area (20 m^2/g). It can be used with cement in quantities up to 5%.

Fig. 7.13 Improper disposal will only increase quanity of waste as the contaminated soil will also require treatment

Ash from rice husk was found to contain pozzolanic materials for addition to cement (Ajiwe and Okeke 2000; Cisse et al. 1998; Real and Alcala 1996; Riveros and Garza 1986) (Fig. 7.13).

7.5.2 Incineration and Coincineration

Incineration is a widely used method for combustible hazards. Incineration can be done in any of the following kiln or combusting devices: (1) multiple hearth, (2) fluidized bed, (3) recirculating fluidized bed, (4) liquid injection, (5) fume, (6) rotary kiln, (7) cement kiln, (8) large industrial boiler, (9) multiple chamber, (10) cyclonic, (11) auger combustor, (12) two stage combustor, (13) catalytic combustion, (14) oxygen enriched, (15) molten salt combustor, and (16) moving belt combustor.

Modern incinerators combine solid-waste combustion with heat recovery. The heat recovery can be done to generate steam or to dry leachate and slurries. The air from incinerators will pass trough *air-pollution control system*.

The rotary kiln incinerator is widely used as it can be used for a wide variety of wastes including liquid and gaseous waste.

A rotary kiln system is shown in Fig. 7.14 and close view of kiln is shown in Fig. 7.15. It includes requirements for feeding, air injection, ash collection and air pollution control. A rotary kiln system can be constructed with a waste heat boiler for the purpose of recovering energy. The waste heat boiler decreases the temperature of the gas thereby allowing use of fabric filter, for particulate control. Apart from bagfilter, other air pollution control equipment employed with incinerator include wet/dry scrubber. Electro Static Precipitator (ESP) is not suitable in presence of combustible material in hazardous waste. The induced draft fan is

Fig. 7.14 Hazardous waste incinerator

Fig. 7.15 Close up view of a rotary kiln

Fig. 7.16 A Cement Kiln

provided to maintain a negative pressure in the system to avoid leaking of a gas out of the kiln system.

The manufacture of cement, light aggregate etc., use rotary kilns. The use of these kilns for destruction of hazardous waste is practiced since long time. Cement kilns (Fig. 7.16) operate at a temperatures of 1,400°C to 1650°F and provide long residence time which is sufficient to destruct Principal Organic Hazardous Constituents (POHCs).

Cost of thermal energy in cement manufacturing contributes to about 30–40 % of the cost associated with cement production hence co-processing of hazardous waste in the cement industry is a viable concept. Cement kiln co-incineration reached nearly 50 % of the market share with respect to hazardous waste incineration in France (Ian and David 2002). In some countries the plants operate with nearly 60% alternative fuel (Battelle 2002).

Some of the co-incinerating facilities avoid some wastes, e.g., (1) nuclear waste, (2) asbestos-containing waste, (3) wastes containing heavy metals, (4) electronic scrap, (5) explosives, (6) mineral acids, (7) medical/Infectious waste, (8) chemical or biological weapons, (9) entire batteries, and (10) unknown or non-specified waste, (11) material restricted by local regulation. Such wastes are avoided usually because of one or many of the following reasons: (1) personnel in cement kilns are not sufficiently skilled to handle some type of waste, (2) kilns are not equipped with proper pollution control equipments, (3) limited knowledge about the consequences of incinerating waste, (4) sentiments of the customers use of biomedical waste comprising body parts during manufacture of cement, (5) local legislation, (6) business risk, (7) logistics, (8) impact on quality of final product, and (9) safety issues.

Waste can be introduced into cement kiln via: (1) the main burner located at the outlet end of rotary kiln, (2) feed chute at inlet end (for lump fuel), (3) secondary burners to the riser duct, (4) precalciner burners, and (5) feed chute to the precalciner (CPCB 2011).

7.5.3 Landfill

Even though incineration is a preferred mode of disposal, landfill is the best available technology as on date for non-combustible waste. Hazardous waste has to be land filled in landfills constructed and operated exclusively for the purpose. Unlike in MSW landfill (where no descrition is made about different waste), hazardous wastes are tracked from the source till they are placed in mappable units called cells (Fig. 7.17). These cells are formed in order to avoid placing of incompatible substance adjacent to each other which could lead to hazardous reactions. Drummed wastes are usually aligned and covered with other wastes which are compatible with each other. Drums may be placed in single lifts or stacked.

Fig. 7.17 Arrangement of non-compatible waste types in a hazardous waste disposal site

Use of daily cover may not be feasible in hazardous waste landfill sites as the placement of uncontaminated clean soil uses landfill space. Further daily covers create anisotropic environment leading to seepage along daily cover. Hence, in order to overcome operational difficulties the landfilled areas are covered with geomembranes to avoid entry of rainwater in the hazardous waste already placed in landfill.

7.5.4 Precautions and Practices During Incineration and Land Filling Hazardous Waste

The major precautions to be taken during handling hazardous waste are the compatibility, reactivity, combustibility and explosivity of the waste. High precautions have to be taken to know what is being fed into an incinerator. Explosive chemicals might not only damage the facility but also affect life. Reactive and corrosive materials often affect the material of construction on incinerator and lining material of landfills. Hence precautions have to be taken with respect to the lining material and chemicals that reacts with lining material. The poor maintenance and operation of air pollution equipments in hazardous waste incinerator would often emit toxic gases. Properties of these gases may not be fully understood yet by the scientific community. The location of disposal facility has to be considered after knowing sensitivity and disaster vulnerability of the location. The knowledge of the staff operating the facilities is also important and any accident or unsafe incidents could lead to loss of lives and property.

Record keeping is also important with respect to the waste disposed. The source and characteristics of hazardous waste in different cells within the land fill shall be properly recorded as it will be essential in later date if there is any damage to lining or landfill due to unavoidable circumstances.

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Chapter 8
Waste From Electrical and Electronic Equipment

Waste from electrical and electronic equipment (WEEE) implies discarded electrical and electronic equipment (EEE). While WEEE includes non-electronic goods, E-waste includes waste from only electronic goods. Some literature does not make differentiation between the two.

The electronic business is the world's fastest and largest growing manufacturing industry (Radha 2002; DIT 2003) and so is WEEE the most rapidly growing waste stream (Widmer et al. 2005; BAN and SVTC 2002) in the world. It is a crisis born from toxic components of the waste posing threat to environmental and human health. WEEE is harmful and valuable as it contains large quantities of environmental contaminants and valuable materials (Morf et al. 2007; Robinson 2009). Whilst e-waste recycling in developing nations is market-driven, it is driven by principles of extended producer responsibility (EPR) in the developed nations.

As per e-waste (Management and Handling) Rules 2011 of India:

> 'e-waste' means waste electrical and electronic equipment, whole or in part or rejects from their manufacturing process, which is intended to be discarded.

As per the Waste Electrical and Electronic Equipment Regulations 2006 of the UK :

> "waste electrical and electronic equipment" means electrical or electronic equipment which is waste within the meaning of Article 1(a) of Directive 2006/12/EC, including all components, subassemblies and consumables which are part of the product at the time of discarding.

The Basel convention calls on all nations to lessen export of hazardous wastes to the least amount and, tackle their waste problems within national borders.

WEEE recycling sector is largely unregulated. However WEEE recycling operations in India, China, and Ghana have been well recorded (BAN and SVTC 2002; Brigden et al. 2005, 2008).

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The production of EEE is the fastest-growing due to intense marketing, technological innovation, and intense replacement process. Brett (2009) estimated that every year, about 20–25 million tonnes of WEEE are produced globally. But UNEP estimated the world's production at 20–50 million tonnes annually (UNEP 2006). The contribution of an item to WEEE production depends on the number of units in service, the mass of the item, and its average lifespan. Figure 8.1 shows reasons for generation of WEEE.

Presence of heavy metals (like mercury, cadmium, and lead), flame retardants (like pentabromophenol, polybrominated diphenyl ethers (PBDEs), tetrabromobisphenol-A (TBBPA), etc.) and other harmful chemicals in WEEE is a major health and environmental concern.

8.1 Significance

The hazardousness of WEEE is well recognized (Oyuna et al. 2011). WEEE contains over 1,000 different substances (BAN and SVTC 2002) and handling of these wastes causes pollution and affects human health especially in the developing world. The potential negative health and environmental impact of improper handling and treatment of WEEE is well documented (Fishbein 2002; Puckett et al. 2003; Ramesha and Ravi 2009; NEP 2006).

Many developing countries which do not have proper solid waste management systems often neglect the hazardous WEEE thrown along with domestic non-hazardous waste. Such practice increases quantum of hazardous waste as non-hazard waste would br contaminate with chemicals like mercury. Figure 8.2 shows consequences of improper disposal of WEEE.

Even though WEEE collection and recovery have gained significance in Europe in the past 15 years, detailed studies quantifying the environmental loads are still rare (Wäger et al. 2011). Cobbing (2008) estimated that mobile telephones, computers and television sets would account 5.5 million tonnes of WEEE in 2010, which would rise to 9.8 million tonnes in 2015.

Estimated WEEE generation to be 1—3 % of the world's municipal waste generation of 1,636 million tonnes per annum, whereas in rich countries, WEEE may constitute about 8 % by volume (Widmer et al. 2005). The fraction of plastics in EEE has continuously increased from about 14 to 18 % in 1992, 22 % in 2000 and estimated 23 % in 2005 (APME 2001). The plastics from WEEE from Europe were estimated to be 20.6 % in 2008 (Huisman et al. 2008). Different literature draws different destination to WEEE. Most discarded WEEE go out with domestic waste and do not receive particular treatment (Ladou and Lovegrove 2008). Electronic equipment which is of no use to the original buyer ultimately exports some WEEE to poor nations (Puckett et al. 2005). In fact, 80 % of WEEE collected is exported to poor nations according to Schmidt (2006). Old functional electronic goods are frequently transported to developing nations with electronic equipment that are not functioning (Ladou and Lovegrove 2008).

Obsolete technology		Due to fast growing technology (hardware and software) old electronic goods become obsolete, e.g., electronic storage device like floppy discs are no more in use and new computer will not have drives to insert them making many of unused floopy becoming waste.
End of Life		Electronic goods usually have a life time of 5 to 10 years after which it will malfunction or stop functioning. End of life of cells, printer drum and cartridge may expire within few weeks from the date of using them.
Energy inefficiency		Most of the old electric and electronic goods are energy inefficient and hence are discarded to save energy.
Damage		Damage to electrical and electronic goods accidentally or intentionally will result in E-waste.
Discontinuing manufacturing Goods, consumables and spare part		Many manufacturer intentionally discontinue manufacturing some of their products and spare parts to create new market to their new products. This would result in discarding equipments even in good condition due to absence of conumables like printer cardridge.
Out of fashion		With invention and design of new equipments, old equipment looks out of fashion and out dated. Hence the user of old equipment will switchover to new equipment. Such rapid changes are seen dominantly with respect to mobile phones.

Fig. 8.1 Reasons for generation of WEEE

Increase in quantity of hazardous waste

Entry of WEEE into waste will increase toxicity and hence hazardous nature of the entire waste into which it enters increasing the hazardousness of the waste

Biomagnifications and entry of chemicals in food chain

Entry of WEEE into environment will increase toxicity and will lead to biomagnification in living organisms and enters human food through dairy, polutry and meat.

Increase in Sharps

Broken glass, plastic and teared metal will increase the sharp objects in waste leading to increased risk of injury.

Contamination

Presence of heavy metals like residual lead in the heap of lead-acid batteries will reach surface/groundwater leading to contamination of water/soil

Fig. 8.2 Consequences of improper disposal of WEEE

8.2 Characteristics and Quantity

The rapid rate of technological change, the high dependence of electronic and electric goods in everyday life and drop in prices has created huge market for EEE. Global quantities of WEEE are increasing across the globe (Ongondo et al. 2011). According to many, there is a drop in the lifespan of electronic and electrical goods and illegal transboundary movement of WEEE (Brigden et al. 2005; Cobbing 2008; Deutsche Umwelthilfe 2007; Puckett et al. 2003).

Due to the inadequate data in many countries flows of WEEE is not quantified. Furthermore, such assessments are expensive and very complex. The substitute of CRT monitors with LCD will decrease the lead in WEEE (Puckett et al. 2005) but, LCD displays will have mercury (Mester et al. 2005), indium, zinc and tin (Li et al. 2009). Rechargeable batteries contain nickel metal hydride (NiMeH), lithium ion, nickel cadmium (Ni–Cd).

WEEE contains a numerous hazardous material including heavy metals (like cadmium, mercury, lead, etc.,) flame retardants (like pentabromophenol, TBBPA, PBDEs, etc.). Mercury is used in switches and relays, gas discharge lamps and batteries (NEWMOA 2008). Batteries with mercury and rechargeable batteries with cadmium, lithium and lead are of concern from environmental point of view (EPS Canada 2006). PCBs contain lead, antimony, beryllium, cadmium, brominated flame retardants, copper, gold, silver, mercury and palladium etc. (AEA 2004; EPS Canada 2006; OECD 2003). Lead acid batteries are commonly used in mobile phones, portable (notebook/laptop) computers, portable power tools, video cameras, etc.

Iron and steel account for nearly half of the total weight of WEEE. Plastics represent about 21 % of WEEE and non-ferrous metals represent about 13 % (Widmer et al. 2005). An older polychrome CRT can contain 2–3 kg of lead, whereas a more recent CRT usually contains less than one kg of lead. The electron gun of the CRT contains barium and barium compounds (OECD 2003). Fluorescent phosphors containing zinc, a cadmium and rare earth metal, is coated on the interior of CRT panel. Figure 8.3 shows composition of desktop computer with CRT.

A notebook PC display can have nearly 0.5 g of liquid crystals whereas mobile phone display can have nearly 0.5 mg. Liquid crystals are implanted between layers of electrical control elements and glasses. About 250 substances are used for making about a thousand marketed liquid crystals. Past studies have not confirmed carcinogenic potential even though the materials used for liquid crystals cause acute oral toxicity, corrosiveness, irritant to the skin (AEA 2004).

Polyvinylchloride (PVC) is the widely used plastic in electrical and electronic goods which are known to emit dioxins and furans during combustion at temperature less than 1,200 °C. Brominated flame retardant (BFR)s are used in some plastics to reduce the flammability and are found in many electronic goods (Birnbaum and Staskal 2004).

It is estimated that worldwide, 20–50 million tonnes of WEEE is disposed annually with the Asian nations disposing off about 12 million tonnes (Greenpeace NA). Total quantity of WEEE generated globally is estimated by UNU (2007) to be 40 million metric tonnes per year. As per the studies conducted by Dalrymple et al. (2007) the EU countries discard about 6.5 million tonnes of WEEE per year with nearly 16–28 % growth every 5 years. Discarded quantity of WEEE in the EU could be as high as 12 million tonnes by 2015 (Goosey 2004). WEEE makes up to 1.5 % of the domestic residual waste in Germany (Dimitrakakis et al. 2009). The amount of WEEE from Germany is between 1 and 1.4 million tonnes/year. In 2006, 1.8 million tonnes WEEE is generated by German market (FEA 2008) and about 750 K tonnes WEEE is reported as returned (Janz and Bilitewski 2009).

WEEE is one among the fastest increasing waste streams in the UK (POST 2007) with about 940 K tonnes of domestic WEEE disposed in 2003 (Dalrymple et al. 2007). Ketai et al. (2008) estimated that around 4 K tonnes of WEEE are disposed throughout the world every hour out of which 80 % is exported to Asia. Every year, households dispose about one million tonnes of WEEE. In 2009,

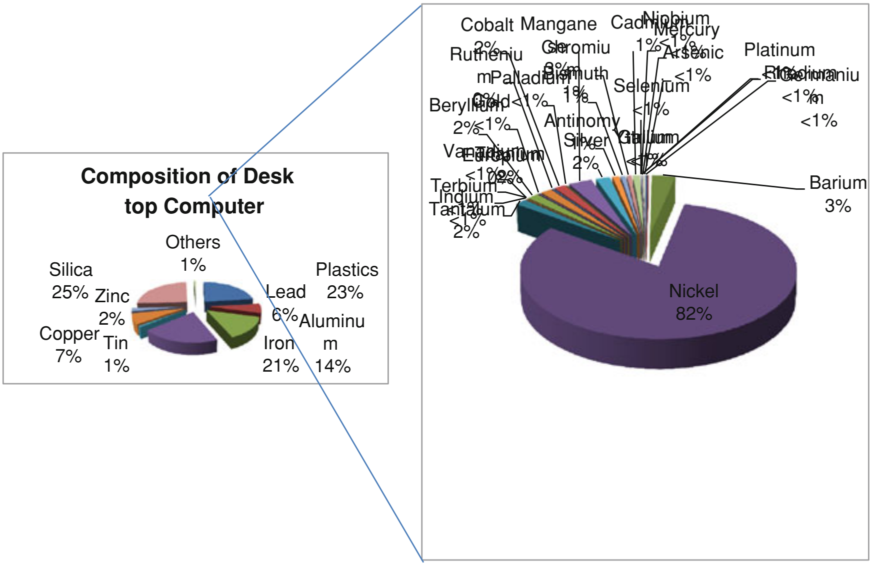


Fig. 8.3 Composition of desktop computer with CRT

about 1.5 million tonnes of EEE was placed in the UK market and about 454 K tonnes of WEEE was collected (Environment Agency 2010).

WEEE accounted for nearly 2.6 % of the overall municipal solid waste stream in Switzerland, during the year 2003 (Khetriwal et al. 2009) and processed about 40,000 tons of WEEE during 2004 (Streicher-Porte 2006).

The 1980s saw a surge in electronic good consumption in China (Yang et al. 2008) and after two decades these goods would have reached the end of their useful lives (Li et al. 2006). As per Schluep et al. (2009), about 2.4 million tonnes of EEE were put in the market of China in 2007 and 2.2 million tonnes of WEEE were produced. According to Xinhua News Agency (2010) about 40 million mobile phones, 25 million TVs, 12 million computers, 10 million washing machines, 6 million printers, 5.4 million refrigerators and 1 million air conditioners were thrown out in 2009.

As on 2011 China was the largest producer, consumer and exporter of electronic and electrical goods and it generated 1.7 million tons of WEEE in 2006 (Xinwen et al. 2011). The figure is expected to reach to nearly 5.4 million tons by 2015 (Yang 2008). Increase in domestic EEE consumption results in corresponding, time-delayed increase in WEEE (He et al. 2006; Liu et al. 2006a). China receives nearly 70 % of all exported WEEE (Liu et al. 2006b), while remarkable quantities are also received by Pakistan, India, Vietnam, Malaysia, Philippines, Ghana and Nigeria (Puckett et al. 2005) and probably to Mexico and Brazil too. As per Schmidt (2006) about 500 shipping containers with electronic goods are transported through Lagos every month. As per Wang et al. (2009) obsolete Personal computers would reach 93.36 million units, absolute TVs would reach

74.31 million units and air-conditioners would reach and 63.9 million units in 2012. China is receiving continuously e-waste from US, Europe and other Asian countries (Puckett et al. 2002; Terazono et al. 2004; Hosoda 2007). Electronics industry is main economic driver of China (Manhart 2007) and is growing fast since 1980s (Yang 2008).

People rarely discard their used EEE in many developing countries even when they are broken or out of date due to a perception that the items could be useful in the future. Most of the times the EEE will be repaired and used for many years unlike the developed countries where the EEEs are disposed of as soon as new attractive EEE goods appear in the market. Another reason for not disposing is lengthy procedure to be followed in many of the government organisations and universities where the absolute and unused electronic goods remain for long time even when they are not used.

As per Jinglei et al. (2009) China is the largest exporter of EEE and also the largest importer of WEEE in the world importing about 35 million tonnes of WEEE from developed nations. As per Yang et al. (2008) it is not apparent how much WEEE is imported into China.

In another developing country, India, the situation is not different either. In addition to illegal imports, domestic WEEE is generated significantly in India (Sepúlveda et al. 2010) with about 50 K tonnes of WEEE imported per year (Manomaivibool 2009). The amount of EEE in the Indian market during 2007 was about 823.6 K tonnes and WEEE generated was about 439 K tonnes (Schluep et al. 2009). Even though some of the used goods are reused, most of the imports are intended for the backyard recycling (Manomaivibool 2009). Common practice in India is to import WEEE as ‘‘reusable'' products, ‘‘mixed cable scrap'' or ‘‘mixed metal scrap'' (Manomaivibool 2009).

About half of the End of Life (EoL) EEE are exported to Asian nations like China, Philippines, Afghanistan, Malaysia and Cambodia as second-hand goods (Shinkuma and Huong 2009; Yoshida and Terazono 2010).

Except in South Africa, WEEE recycling in Africa is rare (Nnorom and Osibanjo 2008). Growth in information and communications in the past decade and import of about 15–45 K tonnes/annum of the unusable computer hardware are two major contributing factors of WEEE in Nigeria which are burnt to reduce the waste quantity (Osibanjo and Nnorom 2007). Schluep et al. (2009) estimated that the quantity of EEE that entered South African market in 2007 was 99 K tonnes per year. Access to the EEE in the last decade has risen in South Africa with nearly 1.5 million computers entering its market every year (Lombard and Widmer 2005). Senegal is importing new and second-hand computers (Rochat and Laissaoui 2008). About 15 % of the computers imported to the nation are used in Uganda. An estimated 5.4 K tonnes of EEE was put in the market of Kenya in 2007 and about 7.4 K tonnes of WEEE were produced in the same year (Schluep et al. 2009).

Brazil generated 679 K tonnes of WEEE 2006 whereas Mexico generated about 28 K tonnes of IT waste in Mexico. Colombia generated about 6–9 K tonnes of computer waste in 2007 whereas Peru generated about 7.3 K tonnes per annum and Chile, generated about 7 K tonnes WEEE in the same year (Silva et al. 2008). As per the Environment Protection Agency of the USA, about 235 million units were accumulated in 2007 (EPA NA). Canada produced about 86 K tonnes of WEEE in 2002 (Environment Canada 2003).

The global WEEE will change with economies and technologies are developed as the total number of computers and other electronic goods are strongly correlated with a country's GDP.

8.3 Material Recovery, Treatment and Disposal

Once WEEE is transported to a materials recovery facility (MRF) the wastes are sorted. The sorted items can be divided into reusable or recyclable categories. There is huge evidence that the repair which was practiced in the USA during two decades ago is now not economical. As per the US EPA (2000) TV repair industry in the USA employed 588,000 people in 1997. But as per Hai-Yong and Schoenung (2005), there is a decline in the industry. Hence the MRFs receive huge quantities of WEEE wherein valuable components are segregated and sold.

Recycling activity contain the following main steps: (a) disassembly, (b) upgrading, and (c) refining (Cui and Forssberg 2003). Figure 8.4 shows a schematic diagram of the steps at a materials recovery facility. Figure 8.5 shows process diagram for disposing of CRT. Some facilities may skip some steps depending on sophistication of unit. Some of the WEEE recycling and disposal activities in the developing world are highly polluting engendering human health. Such polluting activities involve burning of wires and other electronic component to segregate metals, manual crushing of electronic/electrical goods and cells (Table 8.1 and 8.2) for recovery of metals, manual segregation of plastic, glass and other components, and immersion of electrical and electronic goods in chemicals manual.

The magnitude of material recovery at a MRF depends on the size of the facility as well as the target electronic products (IAER 2003). The market for recovered material varies from country to country. More than 50 % of the WEEE from developed countries is exported to developing countries like China, India, and Pakistan as there is great demand in these countries for reuse and recycling of electronic components.

Disassembly is usually carried out manually to recover components like casings, CRTs, external cables, batteries, PCBs, etc. These components are tested and the components which are functioning are sent to secondary market like repair shops, electronic goods assemblers, and electronic goods servicing agencies.

Cathode ray tubes are main item in electronic recycling because of their volume, disposal limitations and recycling costs. Figure 8.6 shows typical storage and dismantling units.

A CRT consists of two main parts: (1) the glass components comprising of funnel glass, solder glass, panel glass, neck, and (2) The non-glass components

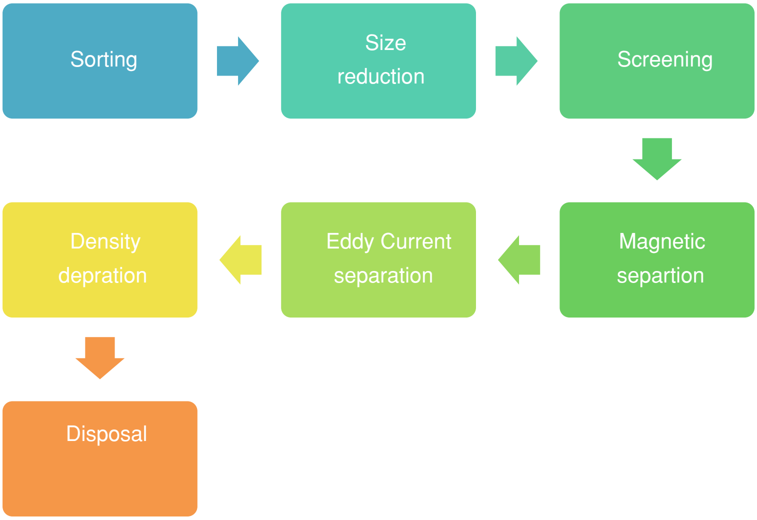


Fig. 8.4 Schematic diagram of steps at a materials recovery facility

Table 8.1 Commonly used rechargeable batteries

Type	Major components	Uses
Nickel–Cadmium (NiCad)	Nickel, Cadmium, Potassium Hydroxide	Power tools, cordless phones, professional radios
Nickel Metal Hydride	Nickel, some "Rare Earth" metals, Potassium Hydroxide	Power tools, cordless phones, professional radios
Lithium Ion	Lithium, cobalt oxide	Computers, cellular phones, digital cameras
Rechargeable Alkaline	Zinc, Manganese Dioxide, Potassium Hydroxide	Flashlights, radios, toys, remote controls, portable radios and televisions, garage door openers
Small sealed lead-acid	Lead, sulfuric acid	Alarm systems, emergency lighting. Some toys and other miscellaneous devices
Vanadium redox	Vanadium pentaxide	Electric vehicle
Lead acid Battery	Lead, lead oxide, sulphuric acid	Vehicle

comprising plastics, electron gun, steel, copper, phosphor coating. CRT glass consists of NaO, SiO_2, CaO, ZnO, BaO, K_2O, MgO, PbO.

There are two technologies available as on date for CRT recycling: (1) glass-to-glass recycling, and (2) glass-to-lead recycling.

In glass to glass recycling whole glass is ground without separation of funnel and panel glass. In the glass-to-lead recycling process, copper as well as lead in CRT glass are separated and recovered through a smelting process. Disassembly is

Table 8.2 Commonly used non-rechargeable batteries

Type	Major components	Uses
Carbon–Zinc or Zinc Carbon	Zinc, carbon, ammonium chloride	Flashlights, toys, remote controls clocks, and smoke detectors.
Alkaline Manganese	Zinc, manganese Dioxide, Potassium hydroxide	Flashlights, radios, toys, calculators, remote controls, portable radios and televisions
Alkaline Manganese button cells	Zinc, manganese Dioxide, Potassium hydroxide	Watches, calculators, toys, some cameras
Lithium	Lithium, Manganese Dioxide or Polycarbon monofluoride, solvent	Cameras, pagers, keyless locks
Aluminium Air	Aluminium	Military applications
Zinc Air	Zinc, carbon	Hearing aids, pagers
Mercuric Oxide button batteries	Mercuric oxide, Zinc, Potassium Hydroxide	Hearing aids, watches,
Mercuric oxide Battery larger	Mercuric oxide, Zinc, Potassium Hydroxide	Specialized industrial, medical, emergency equipment
Nickel oxyhydroxide battery	Nickel oxyhydroxide, manganese dioxide and graphite	Flashlights, radios, toys, calculators, remote controls, portable radios and televisions
Silver Oxide	Silver oxide, zinc, potassium hydroxide	Watches, calculators, toys, greeting cards, musical books

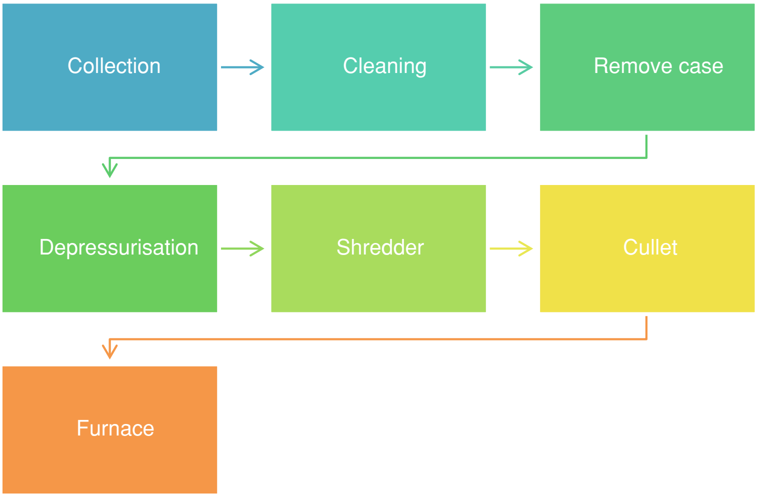


Fig. 8.5 Process diagram for disposing of CRTs

followed by upgrading and refining stages involving mechanical and metallurgical methods. Mechanical processes involves shredding or crushing process to obtain fractions based on their physical characteristics, like size, weight, density, shape, and magnetic and electrical properties.

Usual segregation processes involved are magnetic separation for ferrous parts, Eddy current separation for nonferrous materials.

A magnetic separator uses a permanent or electric magnet for separation of ferrous materials. The overhead belt magnet is the most widespread magnetic separation system. Shredded material particles are moved over the magnet on a conveyer belt where the ferrous metal pieces will adhere to due to magnetic attraction while the other material fraction are dropped into a non-ferrous material collection system/bin by gravity. Ferrous metal pieces remain attached to the belt which are carried away and dropped into a collection container/system when they are no longer influenced by the magnetic field.

Magnetic fraction which dominantly contains ferrous materials would be sent to a steel plant or foundry. Aluminium and copper fractions will be used in recycling industry of respective metals. Plastic fraction will be used in plastic recycling industry. In the case of plastics which cannot be melted they will be used in products like acoustic panels used for interior of auditorium or false ceiling. Crushed glass will be used by glass article manufacturers.

Eddy current separators are employed for non-ferrous metals from non-metallic fractions. When a non-ferrous metal passes above the separator, the magnets in the shell rotate at high velocity. This forms eddy currents in nonferrous metal which in turn create magnetic field around the nonferrous metals. The polarity of magnetic field will be the same as that of rotating magnet, causing nonferrous metals to be repelled away from magnet. Such repulsion results in the trajectory of the non-ferrous material greater than that of non-metal fraction, allowing the nonferrous and non-metal streams to be separated. The ratio of electrical conductivity and density of the material is main criteria for eddy separation. The materials with higher ratio of conductivity to density will be separated easily compared to those with lower ratios.

Aluminium is easily separated in eddy current separator. Stainless steel, glass and plastic have a zero value for conductivity-to-density ratio implying that these materials cannot be segregated by an eddy current separator. Non-ferrous metal embedded in a non-metallic substance (for example copper and aluminium wire embedded with insulation) cannot be separated using eddy current separator.

Plastics are coated/mixed with additives in order to make it flame-retardant. Presence of such additives acts as a barrier for recycling plastics. As the recyclers need a steady supply of the similar type of plastic, it will not be possible to meet such demands because each electronic good uses different types of resin/colour/additives.

The degree of environmental and health impacts vary greatly depending on the technology adopted in the treatment and disposal of WEEE. For example, the possible hazard associated with disassembly stage accidental spillages and releases of hazardous substances like mercury (Aucott et al. 2003). Similarly, the risks involved in handling of CRTs are the risk of implosion because of vacuum in the tubes and inhalation of phosphor coating of the CRT glass.

Storage

Dismantling units

CRT dismantling units

Fig. 8.6 Typical storage and dismantling units in WEEE processing units

Printed circuit board undergoes shredding, grinding to produce dusts of the material being shredded which includes plastics, ceramic, metals and silica (MJC 2004). As per the studies in a US based electronics recycling facility by Peters Michaud et al. (2003) concentration of cadmium and lead levels in air were found to be 0.27 and 1.4 $\mu g/m^3$, respectively. Presences of BFRs in the fine dust fraction recovered were reported by Morf et al. (2005) in the off-gas purification system in a Swiss recycling plant of WEEE. Studies by Takigami et al. (2006) in the air of a TV recycling unit revealed that concentrations of BFRs were higher than background levels.

The monitoring of dioxins and furans from combustion has been well documented (Funcke and Hemminghaus 1997; Sakai et al. 2001; Söderström and Marklund 2002; Tange and Drohmann 2005; Vehlow et al. 2000; Watanabe et al. 2008).

Figure 8.7 shows recycling options for managing plastics from end-of-life electronics. It is essential that the paint and coatings be removed failing which properties of recycled plastics would not fetch good economic returns. Chrome

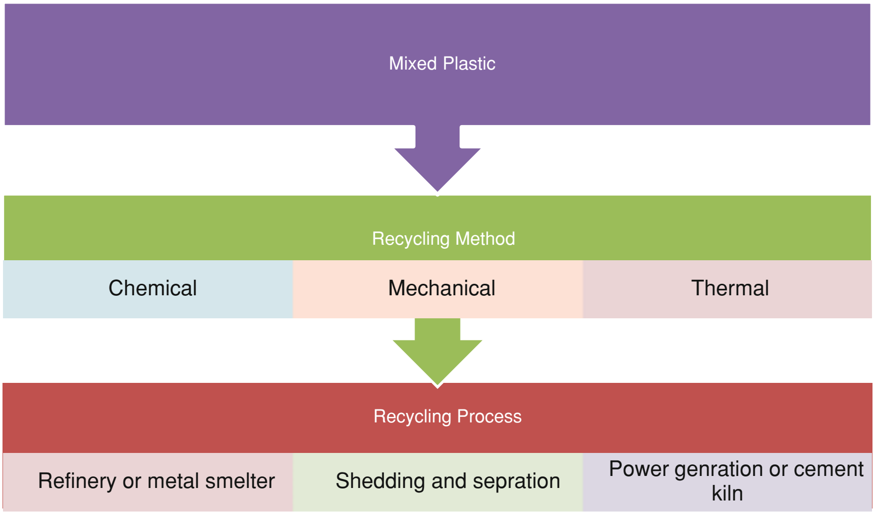


Fig. 8.7 Recycling options for managing plastics from end-of-life electronics

from plated plastics can be grinded and assisted with cryogenic methods to prevent the plating materials being embedded in plastic granules. Abrasive techniques, solvent stripping, high-temperature paint removal methods are the other methods employed for removing coating and paint from plastics (Biddle 1999; Plastic technology 1994).

A reverberatory furnace is usually employed for recovery of lead by charging the furnace with lead-containing materials wherein lead compounds will be converted into to metallic lead and other materials are oxidized to slag. Figure 8.8 shows a process for secondary lead recovery. Slag from a reverberatory furnace is charged to blast furnace with iron and limestone as fluxing agents to enhance furnace efficiency.

Copper is recovered in blast furnace wherein scrap with the copper is reduced by reducing agents like scrap iron and plastics. Figure 8.9 shows processes for secondary copper recovery. The product from the blast furnace called black copper is fed into the converter for oxidation. Blister form converter with copper purity of 95 % is fed into an anode furnace, wherein coke or wood or waste plastic is used as the reducing agent. The copper form anode furnace can be further purified in electrolytic refinery.

Precious metals like gold, silver, palladium and platinum are recovered in precious metal refineries. A schematic diagram of precious material recovery processes is shown in Fig. 8.10. Figure 8.11 shows manual segregation of larger fraction of copper pellets and plastic after shredding and screening. Not all WEEE processing plants will be able to recover costly metals like gold, platinum, etc. In such scenario the powdered metal will be sent to sophisticated plants which have recovery facility. The anode slime from the copper electrolysis is leached by

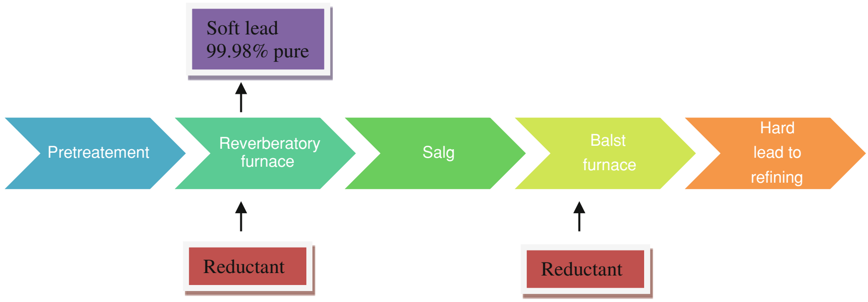
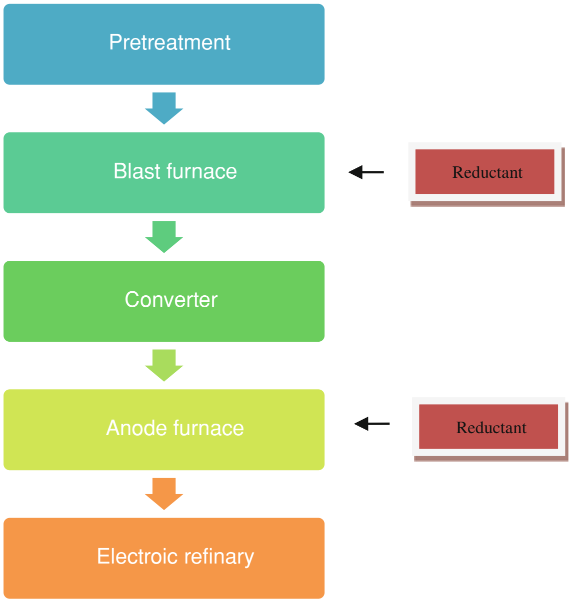


Fig. 8.8 Process for secondary lead recovery

Fig. 8.9 Processes for secondary copper recovery



pressure and the leach residue is smelted in precious metals furnace along with fluxes.

Metallurgical processes involve melting and electroplating. Hydrometallurgical treatment involves acid or caustic leaching of solid material followed by isolation and concentration. Major leaching solvents used for in hydrometallurgical treatment are sulphuric acid, hydrogen peroxide, aqua regia, thiourea, cynide leach solutions, nitric acid, sodium hydroxide, hydrochloric acid etc. (Antrekowitsch et al. 2006). Ion plating is environmental friendly as it avoids chemical solutions. Ion plating is sometimes employed at WEEE processing facilities. It is also called *ion assisted deposition* (IAD) or *ion vapour deposition* (IVD). Ion plating is a

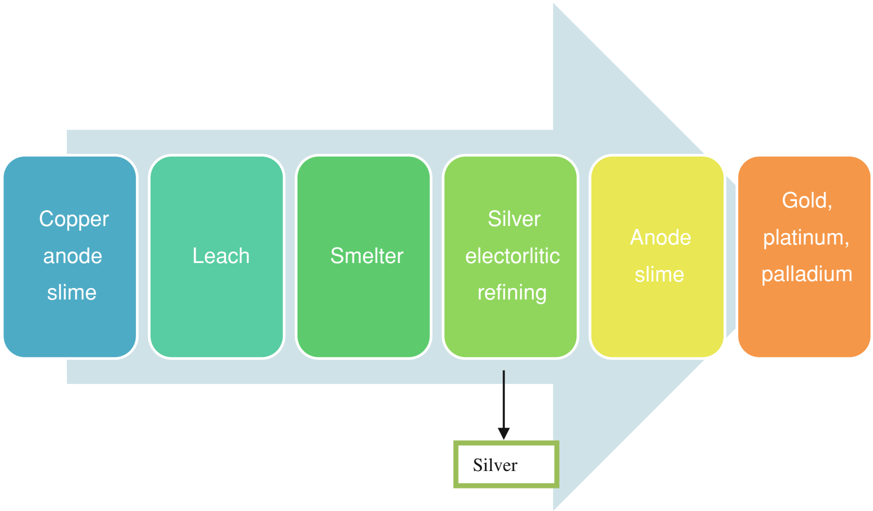


Fig. 8.10 Precious metals recovery process

Fig. 8.11 Manual segregation of larger fraction of copper pellets and plastic after shredding and screening

physical vapour deposition process wherein depositing material is vaporized and films of materials is deposited.

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Chapter 9
Wastes From Industrial and Commercial Activities

In general, waste quantities are an indication of the loss of resources and the hazardous fraction in the wastes indicate the priorities and challenges for efficient waste management strategies. The specific challenges for waste management for municipal and industrial wastes are both similar, and yet uniquely different. Compositions of wastes within each category vary enormously, but as a general rule, industrial waste streams contain a wider variety and more concentrated form of hazardous materials requiring special technologies and handling procedures for them. In both categories of wastes there are major opportunities for prevention and resource recovery. Furthermore, waste-to-energy options exist among those solid waste streams that have high organic contents, which generally is the case for many municipal wastes

Beneficiation followed by melting and molding will generate slag. Further thermal, mechanical, electrical and chemical processes, as appropriate, would change the raw metals to final ready to use products. These products would enter either the households or other industrial and commercial activities. The end of lifecycle of these products would generate waste when the material is no more useful immediately (Fig. 9.1).

Apart from metallic industry, there are huge array of other industries. Economic activities can be classified into primary, secondary and tertiary activity depending on the raw materials used. Primary sector changes natural resources into primary products (e.g., mining, fishing, agriculture). Secondary sector creates a finished, usable product (e.g., car manufacturing, spinning). Servicing industry (like software development), entertainment, transportation, banking etc., form tertiary sectors.

The type and quantity of solid wastes in ports and harbours (Fig. 9.2) may vary considerably depending on the port operations and the types of ships. Consumption by tourists in ocean cruises is done mostly on board whereas only a small expenditure is made on land. Tourists on luxury cruises generate about 3–4 kg/day of waste. Wastes originating at the port include inert wastes from cargo packaging and administrative operations as well as hazardous wastes arising from vehicle

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Fig. 9.1 Sludge from chemical industry

Fig. 9.2 Ports and harbours

maintenance operations. Wastes from ships include oily sludge, food packaging, and food waste. Discharge of solid waste from ships is prohibited in accordance with International Convention for the Prevention of Pollution from Ships of 1973, modified by its Protocol in 1978 and national legislations. But these national/international legislations are overlooked and violated in many instances thereby generating marine debris. Collection and disposal of ship-generated waste are carried out alongside at an anchor. Food wastes from ships should be managed to protect human/animal health. Ports and harbours can generate a variety of wastes which comprise minerals to damaged finished products. Some of the shipments will just lie in the storage area for long time only to learn after it is the waste that has come in disguise.

It is often considered that service industry is not significant from the view point of pollution and waste generation. But the tremendous activities in the service sector can lead to the generation of huge quantities of waste. Quantification of waste from service industry is also difficult as many small size service providers often skip much of the legislation and sometimes may not perform the business

Fig. 9.3 Stagnant liquid in crude storage generates huge quantity of contaminated soil which qualifies to be solid waste

which is on records. For example, a scrap dealer may be just heaping hazardous waste to tip off in the night or a meat merchant may be having slaughter house within his meat stall.

In the tremendously competitive business, solid waste disposal is usually overlooked and solid waste disposal usually accounts for three percent of a manufacturing industry's expenditures.

The major industrial solid wastes generators are: (1) thermal power plants generating coal ash, (2) the integrated iron and steel plants generating blast furnace slag and steel melting slag, (3) aluminum, zinc and copper industries producing red mud and tailings, (4) sugar industries producing press mud, (5) pulp and paper industries generating lime and fertilizer, and (6) industries producing gypsum.

Development of a country is measured through its GDP and other indicators like infant mortality. But the development indicator does not take into account waste recycled/reused. Thus waste management is not considered in calculating Human Development Index.

The wastes from many sectors are raw materials for another sector. Bagasse from sugar industry from sugar can be used by paper industry as raw materials. Scrap metals from automobile industry can be used in foundries. Surplus yeast from bear manufacturing can go to bakeries. Waste meat from slaughter houses can go to kennel food factory. But often these interdependent industries are not located in neighbourhood demanding transportation. Thus the waste which would become resource will remain as waste posing burden to the entrepreneurs who would sacrifice environmental elements rather than their own profits.

Storage of industrial solid waste is a neglected area in the many countries. Figure 9.3 shows stagnant liquid in crude storage which generates huge quantity of contaminated soil that qualifies to be solid waste. Very little attention is given to waste and heaps of waste piled in open ground is a common sight in many industries of developing countries. Disused drums are also used for storage. Transportation of industrial waste in the developing countries is generally not carried out by specialized vehicles built for the purpose. It is typical for an industry

Fig. 9.4 Dried cake of spilled sludge

to have arrangements with contractor quoting the lowest rates. Most of the times the hazardous wastes in the developing countries are collected with other wastes. Drivers in most developing countries are not provided with the knowledge of precautions to be taken. Fly-tipping is often prevalent in these countries as there would be no waste disposal facility.

Characteristics and quantities of the waste depend on the efficiency of the management process. The order of preference in an industry for solid waste management seems to be: (1) avoid/reduse, (2) source reduction, (3) in-process reusing/recycling, (4) on-site resusing/recycling, (5) off-site reusing/recycling, (6) waste treatment, (7) secure disposal, and (8) direct release to the environment.

Characteristics and quantities are often misleading to take any decision. The quantities are often reported on the lower side to avoid statutory obligation to treat and dispose. The backyard of industries in developing countries is huge mess with dried sludge of waste water to slag generated in chemical precipitation (Fig. 9.4). Many a times the waste is buried unscientifically under a layer of soil.

The cost associated with solid waste management can be dramatically brought down by source reduction which is nothing but the reduction of materials entering the system. Example includes buying the raw material with less packaging waste, using pouches instead of bottles for fluids or sending the containers to get it refilled by raw materials, and others.

Reduction and recycling of wastes are site/plant specific and can be achieved by: (1) inventory management and improved operations, (2) modification of equipment, (3) production process changes, and (4) recycling and reuse.

Reuse is another way of reducing the cost. The refilling of printer cartridges is an excellent example wherein the industries in the developing world could save cost by filling ink or toner powder or into cartridge. Another example includes using shredded paper for packaging.

Recycling is another approach where a material is used again and again. The examples for recycling include refilling beverages and cool drinks into the same bottles instead of using metal cans or plastic bottles which are discarded after use.

Fig. 9.5 Precipitated air pollutants often are difficult to collect, treat and dispose

Weather reuse/recycling is done on site or off site it is decided by management depending on the situation. Like agro industry, it often uses waste generated as fuel to generate steam for process or generation of captive power plant with in the plant. Where management cannot invest for reusing and recycling then waste is sold outside for offsite reusing/recycling.

Apart from an industry specific waste treatment, industrial effluents result in the generation of sludge and require proper disposal. Industry may also generate large quantity of waste in the form of precipitated air pollutants (Fig. 9.5).

Small-scale industries in developing countries often contribute more than half the total waste generated there. Small and medium scale industries are often family run or run to overcome unemployment will not able to compete in the market if they spend much of their income on disposing waste. Hence, it is a usual tendency to throw the waste on road side while nobody is watching.

9.1 Extractive Industries

The normal concept of an extractive industry is to convert material from earth and market it in its original form with little or no value addition.

9.1.1 Mining

The mining (Fig. 9.6) is the term used for operating that extract minerals below the ground level. Mining wastes are generated in the process of extraction, beneficiation, and processing of mined material. The waste mainly comprises of barren soils removed during mining and quantity of waste depends on the material being mined and end product extracted at a site. Hence, the lime stone mining will generate less waste compared to diamond mining as former is used completely for cement or

Fig. 9.6 Mining activities

construction whereas later is used for searching small diamond after washing of earthed material.

The extraction and beneficiation generates large quantities of waste. These processes may happen or may not happen at site depending on economics of operation. After the beneficiation the remaining material is usually similar to mined material except change in particle size and chemical constituents can change to depending on the chemical used in the process.

9.1.2 Quarrying

The mining is the term used for operating that extract minerals above the ground level. The operation is done for extracting construction materials in hills, mountains and hillocks. In some sites quarrying is followed by crushing to reduce site of quarried material for easy transportation. In compared to mining, quarrying operations generates small quantity of waste (Fig. 9.7).

9.1.3 Logging

Globally, about 3.6 billion m^3 of round wood was removed from the forests in 2007 out of which 1.7 billion m^3 was industrial round wood and the remaining was fuel wood (FAO 2007). Nearly 30–40 % of the wood would be converted into debris and will not have the same value as that of log. If not managed properly, debris will catch fire and augment the forest fires. The waste from logging will degrade within in the forest and may be collected by nearby villagers as fuel (Fig. 9.8).

Fig. 9.7 Crusher feeder at a quarrying unit

Fig. 9.8 Logs lying for cutting and reshaping

9.2 Basic Industries

Basic industries take raw material form extractive industry. This industry will add value to material generated from extract industry and generates raw material to conversion and fabrication industry.

9.2.1 Metals

The main solid waste generated from metal industries will be in the form of slag. Slag is a by-product of smelting ore to separate the metal. It usually contains a mixture of metal oxides and silicon dioxide, though slag can contain metal sulphides and metal atoms in elemental form.

During smelting metals and impurities are separated by subjecting ore to high temperature. The collection of impurities that is removed is the slag. Ferrous and non-ferrous smelting processes generate different slags. The smelting of lead and copper is designed to remove the iron and silica. Slag from steel mills is designed to minimize iron loss.

Red mud is generated in non-ferrous metal extraction industries like copper and aluminum. Red mud can be used for making corrugated sheets.

9.2.1.1 Copper

The three main steps in copper metal production are roasting, smelting and refining. Roasting is carried to reduce sulphur content. Smelting is carried out to form copper sulphide matte and a siliceous slag. Copper smelting and fire refining generates reverberatory slag amounting to 3,000 kg/MT of refined copper. Dusts from roasters, reverberatory furnaces along with converters are recycled. Electrolytic refinery feed material will have 99.0–99.7 % copper and refined material will have purity of 99.95 %.

Roaster gases are rich in sulphur dioxide and hence they are used for manufacture of sulphuric acid. Blow down from the acid plant will be thickened by sludge thickener and is recycled for metal recovery. Overflow from the thickener as well as miscellaneous slurries from scrubbers, cooling of anodes, washing etc. are settled in lagoon and solids are dredged periodically for recycling (Richard 1978). Slimes from the electrolytic cells are processed for metal recovery and slag from melting furnaces is reprocessed in copper smelter.

Sulphate charge of copper concentrate, coal, limestone, and silica is oxidized in smelt furnace. During smelting both the copper sulphide minerals and slag melt. In addition, exchange reactions take place between the oxides and sulphates of copper and the iron sulphide present in the furnace charge. These reactions occur due to greater affinity of oxygen for iron than for copper. The unoxidized iron sulphide reduces the higher oxides of iron to ferrous oxide. The two layers are separated by heat and time based on specific gravities, followed by tapping the two layers separately. The slag thus separated in settler furnace is granulated with water. In addition, small quantities of anode furnace slag are expected to be generated in blister copper production stage, matter from settler furnaces is fed to the converters. Air is blown through the molten slag which oxidizes sulphur into sulphur dioxide. The end products are blister copper with 98.5 % purity and anode furnace slag. For every tone of copper anode produced, 2.2 tonne of smelter slag is generated.

The converter slag is crushed and ground and is made into slurry (20 % solids) and floated with xanthate and pine oil. The copper concentrate is then collected as froth and filtered on drum filters. The tails are subsequently pumped to the tailing pond. Hygiene ventilation system is provided for safe discharge of fugitive gases emitted from converters, anode furnace and isasmelt and rotary holding furnace. The fugitive gases thus generated contain SO_2 and are desulphurised in multiscrubber in the scrubbing medium of lime solution. The solution is recycled for absorbing SO_2 from the fugitive gases till the required consistency. This process ultimately results in the production of gypsum slurry which is sent to phosphorous gypsum storage pond.

Sulphur dioxide gas emitted from the isasmelt and from the converter with temperature of 1,200 °C is first cooled inside gas cooler to 350 °C and then dust particles are removed in an electrostatic precipitator. Similarly the gases from each converter coming out at 780 °C are cooled separately and dust particles are removed in an electrostatic precipitator. Dust is removed in both the cases in the form of slurry. The slurry will be treated in an effluent treatment plant, where small quantity of metals will be form stable compounds along with gypsum.

Sulphur-dioxide-bearing gases from isasmelt and converters after cooling and cleaning are treated to produce sulphuric acid. This sulphuric acid (98 %) reacts with rock phosphate in phosphoric acid plant to produce phosphoric acid. Hemi-hydrate gypsum is produced phosphoric acid and di-hydrate gypsum as a byproduct. Considerable quantity of chemical sludge is also generated in the effluent treatment plant treating the wastes generated from the phosphoric acid plant. The treatment scheme is made up of neutralization, precipitation of sulphates, phosphates and fluorides with polyelectrolyte at optimum pH, sedimentation of precipitates, pH correction, sludge thickening, centrifuging of thickened sludge etc. Besides the process requirement for scrubbing in various scrubbers, the treatment plant treating waste waters from hygiene ventilation, gas cleaning section, phosphoric acid plant etc., require lime for treatment. The milk of lime (MOL) is proposed to be prepared from lime containing 60 % CaO. Thus, the balance 40 % will be of inert/grit matter (Table 9.1).

9.2.1.2 Aluminum

Aluminum is produced from bauxite. The crushed ore is screened stockpiled, and upgraded by beneficiation before feeding into alumina plant. Beneficiation is done to remove unwanted material like clay and silica. Beneficiation and ore washing generates tailings slurry with 79 % solid waste. At the alumina plant, bauxite ore is crushed and digested with hot sodium hydroxide and after removal of insoluble part of the bauxite and fine solids from process liquor precipitated aluminum trihydrate crystals is calcined fluidized bed calciners or rotary kilns to produce alumina. Some alumina processes involve a liquor purification step. The insoluble part of bauxite separated during digestion is called “red mud”. Hazardous wastes from alumina plant comprise waste descaling in tanks and pipes as well as salt cake produced from liquor purification.

1 to1.5 tons of red mud are extracted for every tone of alumina/aluminium production by the Bayer process. Electrolysis of alumina for production of aluminium is carried out in steel pots lined with refractory bricks and carbon bricks. The life of the linings used in steel pots varies from three to five years and needs replacement afterwards. The lining which has completed useful life in electrolysis

Table 9.1 Solid waste from primary metallurgical industries

Metal	Process	Solid waste kg/T of metal produced
Copper	Reverberatory slag	3000.00
	Acid plant suldges	2.70
	Dusts	17.00
	Miscellaneous slurries	17.00
	Slurries from electrolytic refining	2.40
Lead	Blast furnace slag	410.00
	Slag fines	30.00
	Acid plant sludge	40.00
	Sinter scrubber sludge	19.00
Zinc	Acid plant sludge	17.00
	Sludge from Electrolytic process	9.10
	Retort residue	1050.00
	Acid plant sludge	122.00
	Cadmium plant residue	1.80
Aluminium	Bauxite beneficiation	790
	Alumina plant (Bayer process)	1000–1500.00
	Aluminium smelter	20.00–80.00

Source Richard (1978), IFC (2007a), Sanjay et al. (2006), Nicholas (2003)

pot is called Spent Pot Lining (SPL). SPL constituents two cuts. Cut one is the upper portion (which contains up to 60 percent carbon) and cut two is the lower one-third of the total volume (which consists mainly of alumina or silica brick). The carbon portion of the SPL contains about 0.01–0.025 % leachable cyanide and 2–8 % of leachable fluoride. Apart from the spent pot lining aluminium smelter generates collector bars, black mud and metal plate as wastes which are reused at the time of relining the pots. Black mud is generated during recovery of cryolite from SPL specific waste generation from as aluminium smelter ranges between 43 and 62 kg/tone of aluminium produced. Apart from on-site recovery for carbon, fluorides, cryolite SPL can be used as a raw material in iron and steel making and, cement and red brick manufacturing industries (CPCB 1997).

Red mud and blast furnace slag are major solid wastes generated in Indian metal industry amounting to approximately 3 and 12 million tonnes per year, respectively (Tamotia 2003; LCA Report 2003).

9.2.1.3 Iron and steel

Steel is manufactured by two methods namely the electric arc furnace (EAF) and basic oxygen furnace (BOF). The input materials in BOF are molten iron, scrap, and oxygen whereas the raw materials for EAF are electricity and scrap. Iron making and coke making precede steelmaking in the BOF process.

Pig iron is produced from sintered, pelletized, iron ores using coke and limestone. The iron is then fed to a BOF in molten form with scrap metal, fluxes and

Table 9.2 Solid waste from foundries

Source	Quantity kg/ton of castings
Furnace slag	55–120
Shot blasting dust	30–180
Moulding sand	100–600

high-purity oxygen. In some plants sintering (heating without melting) is done to agglomerate fines. Solid wastes from the BOF process are slag and dust collected in air pollution control equipments (Table 9.2).

Solid wastes from coke oven contain benzene and PAHs. Solid waste from coke oven comprises residues from coal tar recovery (generally 0.1 kg/t of coke tar storage (around 0.4 kg/t of coke), the tar decanter (about 0.2 kg/t of coke), light oil processing (nearly 0.2 kg/t of coke), tar distillation (around 0.01 kg/t of coke), naphthalene collection and recovery (typically 0.02 kg/t of coke), wastewater treatment (approximately 0.1 kg/t of coke), and sludges from biological treatment of wastewater (Nicholas 2003). Wastewater treatment sludges are dewatered and charged to coke ovens or incinerated, or disposed in a secured landfill. Solid hazardous wastes are recycled to a coke oven or fed to combustion unit, or disposed of in a secure landfill (Table 9.3).

The blast furnace (BF) and steel melting shop (SMS) slags from integrated iron and steel plants are also useful raw materials in cement manufacturing. But they have found greater acceptance as road sub grade or for use in flooring and land-filling.

Blast furnace slags which are thrown outside the iron and steel factories can be used in manufacture of slag cement, metallurgical cement, non-portland cement, high early-strength cement and super sulphated cement. Blast furnace slag can also be used as aggregate in concrete and as a structural fill.

Apart from being used to fill low lying area, metallurgical slags can be used as structural fills and in the manufacture of pozzolana metallurgical cement.

9.2.2 Chemicals

Chemical industry has a number of products in the market. The chemical industry converts raw materials such as oil, coal, air, water and minerals, into a vast array of products such as adhesives, catalysts, coatings, paints, varnish, acids, alkalis, plastic adhesives, pharmaceuticals, agrochemicals, soap, detergents, personal care products, perfumes etc. Most of the output from chemical industries is used in other industries.

It is difficult to quantify waste from all the chemical industry as about 12,000 new substances are added to *Chemical Abstract Service* (CAS) each day (CAS, 2011). As on October, 2011 more than 51 million single/multistep reactions and synthetic preparations as well as more than 53 million commercially available chemicals were registered with CAS. Further about 12,000 new substances added to CAS every day (CAS, 2011).

Table 9.3 Solid waste from secondary metallurgical industries

Product	Process	Solid waste kg/T of product
Iron steel	Coke oven sludge	2.60
	Waste ammonia liquor	190.00
	Blast furnace slag	200.00–400.00
	Blast furnace sludge	3.00–5.00
	Basic oxygen furnace slag	85.00–100.00
	Basic oxygen furnace dust	145.00
	Basic oxygen furnace kiln	16.00
	Basic oxygen furnace sludge	0.14
	Open hearth furnace slag	17.30
	Open hearth furnace slag	243.00
	Open hearth furnace dust	13.70
	Electric furnace slag	120.00
	Electric furnace dust	10.00–20.00
	Electric furnace sludge	8.70
	Soaking pit slag	35.20
	Primary mill sludge	1.87
	Primary mill scale	44.90
	Continuous caster sludge	0.10
	Continuous caster scale	8.70
	Hot rolling mill sludge	1.74
	Hot rolling mill scale	70.00–150.00
	Cold rolling mill sludge	0.16
	Cold rolling mill scale	0.05
	Cold rolling mill pickle liquor	22.80
	Tin plating mill sludge	5.32
	Galvanizing mill sludge	10.80
	Galvanizing mill pickle liquor	5.17

Source Richard (1978), IFC (2007a), Sanjay et al. (2006), Nicholas (2003)

Figure 9.9 shows waste waste from a chemical industry stored crudely in plastic bags as against proper storage in drums. Waste from chemical industry mainly comprises of raw material, intermediate compounds and end products along with corroded machine components and packaging material.

Gypsum which is a by product of many chemical industries can be used for manufacture of plaster boards, gypsum plaster, slotted tiles, and cement.

Phosphogypsum generated from the phosphoric acid, hydrofluoric acid plants and ammonium phosphate are useful in making cement, artificial marble, partition panel, ceiling tiles, fiber boards, etc.

The major waste stream from chlor-alkali consists of brine muds from the brine purification process which is likely to contain calcium, magnesium, iron, as well as other metal hydroxides. The muds are filtered or settled, dried and then land filled.

Solid wastes in the nitric acid plant and ammonia production comprises of spent catalysts whereas the fertilizer plants generate little solid waste from as dust and

Fig. 9.9 Waste from a chemical industry stored crudely in plastic bags

fertilizer spillage is returned to the process. The sludges from wastewater treatment plant will comprise of toxic sludges that must be disposed of in secured landfill.

Solid wastes of from dyes and dye intermediate manufacturing plants include process and effluent treatment sludges, filtration sludges and container residues. The waste from dye and dye intermediate manufacturing is incinerated or landfilled depending on calorific value and infrastructure available in the country/region.

9.2.3 Paper

Lime sludge or lime mud is generated in pulp and paper mills along with tree bark, wood fiber, paper pulp, inert filler, trimmings of paper or paper board and waste generated by malfunctioning of equipments. Most pulp and paper manufacturing facilities operate own kilns for regenerating lime after use. Lime is used to reconstitute caustic soda from sodium carbonate left over in the pulp-making process. Lime is used in water softening in paper manufacturing facilities. Very fine precipitated calcium carbonate is used in paper production to increase the paper's opacity, whiteness, and texture. Potential technologies and strategies for managing solid waste from paper industry include source reduction, in-process and off-site recycling, land spread on cropland, daily landfill cover, and energy recovery (Matthew 2009).

The major solid wastes of from pulp and paper industry are wastewater treatment sludges. The quantity of waste from wastewater treatment varies from 50 to 150 kg/t of air dried pulp (World bank 1998). Other solid materials include (1) waste paper, which can be recycled, (2) the bark, which can be used as fuel, and (3) lime sludge and ash, which needs to be disposed of in landfill.

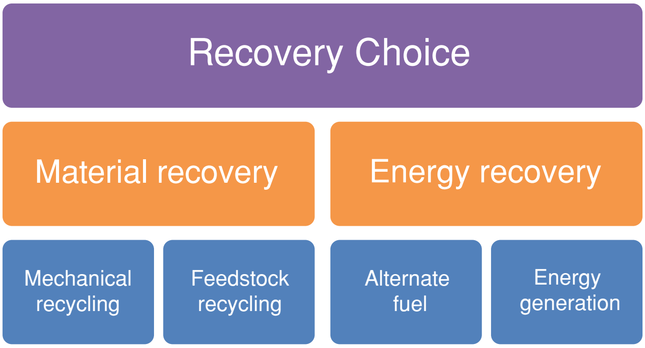

Fig. 9.10 Recovery choices for plastic waste

9.2.4 Plastic

Global production of plastic increased from 1.5 million tons in 1950 to 245 million tons in 2008 (APME 2009) and the Western European countries produced 45.3 million tonnes of plastics (Nzihou 2010). As traditional plastics are resistant to degradation they continue in the environment for long time, and are particularly detrimental to the marine environment (Moore 2008).

Manufacturing of plastic articles is done by melting raw material and moulding. Waste from the industry is breakage, off specification products and trimmings. Such wastes are melted and moulded in the industry itself.

Plastics in wastes can be categorized into following streams as classified in the *European Waste Catalogue:* (1) plastic packaging, (2) plastics in municipal solid waste, (3) plastics from WEEE, (4) plastics from the end of life vehicles (ELV), (5) plastics in C&D waste, and (6) plastics in agriculture. Fig. 9.10 shows recovery choices for plastic waste. Major alternatives for the management of plastic waste are: (1) reusing, (2) land filling, (3) melting and reshaping, (4) feedstock recycling, and (5) energy recovery.

Mechanical recycling is limited due to low purity of product and limited market for recycled products. Energy recovery is the option for contaminated plastic and complex mixture of plastic.

9.2.5 Glass

Solid waste from glass manufacturing unit includes slag from the purifying of glass sand, miscellaneous containers, ash of the fuel, packaging material. Residues from the products used in colouring and breakage during manufacture.

9.2.6 Textile

Waste from the textile industry includes fibres damaged during storage or manufacturing. Major solid waste from the garment industry factories comprises fabric waste from garment cutting amounting to 10–20 % of fabric consumption. Garment cutting involves substantial quantities of paper and plastic. Waste reels/bobbins, thread, elastic etc., amounts to small fraction of total solid waste generated. Waste minimization options include: (1) reducing the quantity of packaging material, (2) purchasing chemicals in returnable drums, and (3) purchasing yarn on reusable cones.

9.2.7 Wood Products

Major waste from wood product manufacturing is tree bark, saw dust, shavings, splintered wood and trimmings. The waste quantity would amount 10–20 % of that of the original tree in the forest. The waste can be reused for making boards or as fuel.

9.2.8 Power

A 1,000 MW station using coal with 3,500 kCal/kg as well as ash content in the range of 40–50 % would required approximately 500 hectares for disposal of fly ash in about 30 years' operation. Fly ash is generated from electrostatic precipitator (Fig. 9.11) constitutes about 80 % of total ash generated in power plant. Other 20 % would be generated as bottom ash and collected at bottom of boiler. In the last decade use of fly ash has increase so much in cement industry that all the fly ash from major thermal power plants are lifted by the cement manufacturers. Addition of fly ash has resulted in the reduction in use of lime stones and added profit to the cement industry.

Fly ash which is often disposed off in ash ponds and ash mounds can be used for the manufacture of cement, bricks and precast building units. The fly ash can be used as a structural fill for roads stabilization of soil and filling in mines. Thermal power plants of India produce more than 100 million tonnes of fly ash (Ashokan et al. 2005; Kumar et al. 2005).

The fly ash can be reused for : (1) as fine aggregate in concrete production, (2) for structural fills in embankments, (3) waste stabilization and solidification, (4) production of cement, (5) mine reclamation, (6) stabilization of soft soils, (7) sub-base construction of roads, (8) brick production, (9) asphaltic concrete, (10) soil amendment, (11) application on rivers to melt ice, (12) application on roads and parking lots for ice control, (13) toothpaste, (14) kitchen counter tops, (15) floor and ceiling tiles, (16) precast structure, and (17) soil conditioner in agriculture.

Fig. 9.11 Electrostatic precipitator

9.2.9 Petroleum

Petrochemical plants generate large quantity of solid wastes and sludges which include hazardous waste due to presence of heavy metals and toxic organic chemicals like acetaldehyde, acetonitrile, benzyl chloride, perchloroethylene, aniline, chlorobenzenes, nitrobenzene, methyl ethyl pyridine, carbon tetrachloride, cumene, phthalic anhydride, toluene diisocyanate, trichloroethane, trichloroethylene dimethyl hydrazine, ethyl chloride, ethylene dibromide, toluenediamine, epichlorohydrin, ethylene dichloride, and vinyl chloride. The major solid wastes from petroleum are (1) spent catalysts, (2) filters, (3) spent amines, (4) activated carbon filters, (5) oily sludge, and (6) neutralization sludges (IFC 2007b).

Combustion preceded by solvent in some cases is considered an effective treatment technology for petrochemical organic wastes. Spent catalysts are usually sent back to the suppliers. Steam stripping and oxidation are used for treating organic wastes. Some solid wastes require stabilization before disposal in landfill.

Management strategies for catalysts include regeneration, on-site storage and handling. Hydrophoric spent catalysts is submerged in water to avoid uncontrolled exothermic reactions. Neutralization sludges they may be marketed for steel mills use or landfilled after drying and compression.

9.3 Conversion and Fabrication Industry

Conversion and fabrication activities include but not restricted to cutting, drilling, welding, rivetting, painting, and die operations. Unlike extractive and basic industries, conversion and fabrication industry generate less waste per unit product manufactured.

Fig. 9.12 Ship building activities

9.3.1 Packaging

Paper, metal, cardboard, plastic, wood, coir, thermo coal and other materials are used for packaging. Thus the waste from packing comprises of metal trimming, imperfect casting, and soiled packaging material. Recovery of the materials depend on the cleanliness of the materials.

9.3.2 Automotive

In spite of being responsible for major carbon emission, this industry has grown tremendously in the developed countries and is slowly shifting toward developing countries. Automotive not only include vehicles on road but also include ship/boat building (Fig. 9.12) and air craft manufacturing industry.

Potential technologies and strategies for managing solid waste from this industry include waste elimination, waste reuse, recycle, and energy recovery. Even though the strategies look fine theoretically, the industry will outsource manufacturing of components with high pollution potential to small and medium scale industry. Thus automobile manufacturing units look cleaner but their impact on environment would have occurred in the component supplier's site.

The solid and liquid waste in ship building and breaking units will have asbestoses, paints, chemicals, metal pieces, plastic rubber etc. Most of the developed countries have stopped ship breaking activities due to hazards associated with them and the solid wastes which do not have economic values would be thrown into sea or fall into sea during building/breaking activities in the developed world.

End of life vehicles (ELV) are vehicles permanently retired. ELVs are associated with the following fates: (1) recycled via the existing ELV vehicle management infrastructure, (2) abandoned in remote or hard-to-reach locations,

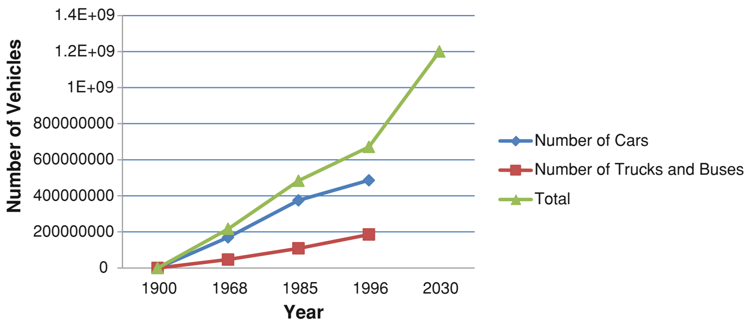

Fig. 9.13 Growth of number of vehicles in the world

(3) lying in the custody of legal organizations like police of transport department as the vehicles would have been seized due to violation of law.

Growth of vehicles based on the data published by (Elert 2001) is given in Fig. 9.13. The materials used by the automobile industry in the USA were 33 million tons in 1993 (Jody and Daniel 2006). The recycling and abandoned rate for automobiles in the USA is estimated to be 94 and 6 %, respectively (AAMA 1997). It was 12.5 million ELVs comprising of 7.7 million cars, 0.2 million medium/heavy trucks and 4.6 light trucks are recycled each year (Jeff and Gregory 2001) in nearly 15,000 dismantling facilities in the USA (Jody and Daniel 2006). Today approximately 2,721,250 cars are completely worn-out in Turkey. This value may reach 3,000,000 if we add the other types of vehicles like the trucks, the motorcycles and similar vehicles (TSI 2007) and ELV vehicle is composed about 68 % iron/steel, 22 % aluminium as well as 8 % other metals (Melek et al. 2011). As per Eurostat (2010) 6.34 million ELVs were processed in the year 2008. As per GHK and BIS (2006) over 10 million tonnes of material is generated in EU in 2005 and will reach 14 million tonnes by 2015.

In the developed countries dismantling can be done by high-value parts dismantler or salvage scrap yards. Both of them will initially dismantle for high-value parts like starters, alternators for resale. Dismantled ELVs are sent to a shredder in flattened form for shredding which is then segregated into ferrous metal and nonferrous materials. Nonferrous material stream is segregated into metal and non-metal fractions. The useless non-metals referred to as automotive shredder residue (ASR) is land filled or sent for incineration.

In the developing countries dismantling is mostly backyard activity which is carried out in open air or primitive workshops.

9.3.3 Electrical and Electronics

Major components electrical and electronics industry include batteries, Cathode Ray Tubes (CRTs), mercury-containing components, asbestos waste, printed circuit boards (Fig. 9.14), liquid crystal displays (LCDs), plastics containing

Fig. 9.14 Waste in electrical and electronic industry

halogenated flame retardants, and equipment containing Chlorofluorocarbons (CFCs). Potential technologies and strategies for managing solid waste from this industry include Product changes, Input-material changes, Technology changes, Operating practices and process changes, Production-process changes, Product reformulations, Recycling and reuse (Matthew 2009).

9.3.4 Paper Products

Manufacture of paper products like paper cups, plates, boxes, toys, bags, books, etc., involve cutting trimming, punching, gluing, and stitching operations. Hence the waste from paper products comprises of paper trimmings and other materials used for the manufacture of paper products.

9.3.5 Hardware

Hardware is confined to the metal industry which produces machines, tools with an excepting of automobile. The solid waste in hardware industry comprise waste from trimming, drilling, milling, punching, plating, etching, painting and other activities include with reshaping metal. The major waste from hardware industry comprises of metal scrap, plastic scrap and packaging waste.

9.3.6 Soft Goods

Conversion of leather, textile and plastics into finished products is termed as soft goods. Residues of the material processed constitutes major portion of the solid waste.

About 8–9 million tonnes of fresh hides are produced in a year (FAO 1990) generating 1.4 million tonnes of solid waste (El Boushy and Van der Poel 1994). The global production of leather was about 24 million m^2 in 2005 (Kanagaraj et al. 2006). Animal skin is composed of 90–95 % of solids by volume (35 % by weight). Skin is mainly made up of proteins, carbohydrates, lipids, mineral salts and water. Among many types of proteins present in the leather, collagen makes the major portion of skin and is responsible for formation of leather by combining with tanning agents. Fleshing waste which constitutes 50–60 % of total wastes can used for manufacture of feed. Chrome tanned leather, trimmings and splits are useful in making glue, gelatin, reconstituted collagen and protein flavor.

9.3.7 Food Processing

About 1.3 billion tons of food are wasted every year globally accounting for one-third of food produced (FAO 2011a, b). Food is wasted from agricultural production to final consumption. In medium- and high-income nations, food is wasted even if it is suitable for human consumption whereas in low-income nations food is wasted in the early/middle stages in the food supply chain (FAO 2011a, b). The reasons for food losses in low-income countries are connected to the limitations in harvesting, storage, packaging, transportation and marketing systems. Per capita food waste in North-America and Europe is 95–115 kg/year whereas in South/Southeast Asia and Sub-Saharan Africa it is 6–11 kg/year. Nearly 23 million tonnes of cereals, 21 million tonnes of vegetables and 12 million tonnes of fruits are lost each year in India (Nellemann et al. 2009). Poverty is the main reason for such huge variation. Lars and Gabriela (1999) observed recovery of edible bread by scavenging community at Bisasar Road landfill in Durban before the operator of the landfill removed the inedible waste for disposal.

Out of the total landings of 100 to130 tonnes/anum discarded fish amounts about 30 million tones. Such large amounts not only generate wastes, they also directly destroy aquatic ecology by stealing away species form a fragile ecosystem (Nellemann et al. 2009).

The causes of food losses in medium/high-income countries are due to consumer behaviour and poor coordination between various factors in the supply chain. Expiring 'best-before-dates' and careless attitude of people who can afford to waste food are also some of the major reasons for food waste. Every year, the United Kingdom homes waste one third of food purchased amounting to 6.7 million tonnes of food (Nellemann et al. 2009). Avoiding food waste is more suitable rather than managing waste as each ton of food generated will consume huge quantity of water, fertilizer, pesticides, packaging, and energy for transportation as well as pumping water. Food waste in medium- and high- income countries can be brought down by raising awareness in all levels of supply chain. In the USA, 30 % of all food is wasted each year and in many African countries

Table 9.4 Examples of usable products form waste

Waste origin	Usable product
Slaughterhouse or meat processing waste	Jellies, animal feed, gelatin, collagen, sialic acid, bone meal, bone charcoal, blood charcoal
Fish and seafood processing waste	Pet food, chitin/chitosan, oils, lipids, antioxidants, flavours and pigment
Fruit and vegetable waste	Oils, flavours, starch, glucose, lycopene, colouring and pectin, cattle feed
Wsate from sugar manufacturing	Press mud and bagasse

25 % of the total harvest is lost (Nellemann et al. 2009). In low-income society food waste can be brought down by creating proper infrastructure in supply chain.

Food industries convert raw materials from plant and animal origins. With the exceptions such as rice husk and bones food waste are degradable and comprises of material processed. Food-manufacturing industry links farmers with consumers by processing grains, fruits, vegetables, meats, and dairy products. Food processing wastes vary from industry to industry depending on finished product. Potential technologies and strategies to manage waste from food industry include food donations, source reduction, animal feed, rendering and composting (Matthew 2009).

Waste materials can be converted into single-cell protein or ethanol. In the first case waste is converted into nutritious food for livestock or by humans. In the second case ethanol is generated for consumption or as a fuel. Microorganisms that constitute the food are strains of the Saccharomyces cerevisae, yeast, or some other edible species. Ethanol generation involve culture of microbes which have a capability to ferment sugars to ethanol.

Unsalable food waste which is fit for human consumption is donated to charity by many manufactures. Recognized food banks need recipients to sign legal documents not to sell exchange or barter food goods received through donation. The types of waste which are unsalable but suitable for consumption include incorrect/damaged labelling, end-of-season stocks, packaging with wrong weight, over-production runs, discontinued products, damaged/unattractive products.

Recovering a product by modification of a process can reduce quantity of solid waste and related disposal costs. Disposal of food as animal feed is common in bread baking, vegetable processing, and dairy processing.

Some of the usable products produced during food process are given in Table 9.4.

To produce 1 kg of meat it takes about 3 kg of grain (FAO 2006) and about 16,000 L of virtual water (Chapagain and Hoekstra 2008). Therefore an increase in the meat consumption and wastage results in rapid demand for water, crop and other resources like land for grazing. Meat production is considered as environmentally harmful and energy inefficient with intense use of feed crops.

Some of the important food processing industry and solid generated in it is discussed in subsequent paragraphs.

Fig. 9.15 Husk generation in rice mill

Fig. 9.16 Ash disposed in open space

Rice: Rice is one of the important food crops in the world. FAO has forecasted global paddy production of 721 million tonnes in 2011 (FAO 2011a, b). The rice husk is separated from paddy before it is used. Dehusking is done in rice mill generating 180–190 kg/ton of husk (Fig. 9.15) per ton of paddy.

The rice husk is used as biofuel in paddy cultivated regions for residential commercial as well as industrial purposes generating huge amount of ash (Fig. 9.16). The ash is mixed with municipal solid waste in residential and commercial areas near its source as it is dumped in open spaces.

Sugar: Global sugar production in the marketing year 2010/11 was estimated at 164 million tons (USDA, USDA (United States Department of Agriculture) 2010). Sugar can be manufactured from sugarcane o sugar beet. Sugar cane is used for 65–70 percent of global sugar production. Sugar cane is crushed for extraction of juice. The resulting fibrous residue of cane which accounts 28–30 % by weight of cane is called bagasse. Bagasse can be used for Paper Industry, particle board or as fuel. Further chemicals are added to juice and filtered prior to crystallization resulting in solid material of around 2 % of weight of sugarcane crushed which is used as manure.

Vegetable Oil: Vegetable oil is manufactured out of various raw materials which include oil palm, coconut, ground nit, olive, sunflower, mustard seeds, almond, rice barn, etc. Vegetable oil manufacturing plants generate solid waste and by-products like empty fruit bunches (EFBs), fruit shells, waste palm kernels, decarted shells, soap stock and spent acids during chemical refining of crude oil, spent bleaching earth, deodorizer distillate from steam distillations, mucilage from degumming, spent catalysts and filtering aid.

EFBs are returned to the plantations for use as soil amendment. Spent bleaching earth can be used as feedstock for brick or block making. Bleaching earth can be used as fertilizer if it is not contaminated with metals. The cake generated during the pressing of raw oilseeds is used as cattle feed.

Meat and Fish packing: Packaging of meat and fish generates discarded meat, hide and skin. Most of the waste is processed to manufacture poultry/animal feed or used for composting/biomethanation.

Fruit Pulp: Fruit pulp is made out of fruits like mango, apple, orange, pineapple, tomato prior to further processing for manufacture of fruit juices, sauce, ketchup, jam, jelly etc. The fruits are first selected washed pealed and pulped. The major waste generated is fruit peel, seeds, and damaged/rotten fruits. The waste generated is easily degradable and can be used for biomethanation or composting.

9.3.8 Construction and Demolition

Wastes from C&D activities comprise of the off specification and damaged bricks or concrete blocks, and building material. The quantity of waste depends on the size of the activity. Apart from the construction activities, brick making and offsite activities like carpentry and fabrication would also generate huge amount of waste. The waste from brick waste mostly comprises of ash and low quality material. The stone cutting and polishing activities carried out offsite will also generate huge slurries which are later let out for drying or dried and dumped in outside the industries in many developing countries due to poor implementation of legislation or absence of legislation.

C&D wastes comprise of: (1) waste from the total/partial demolition of civil infrastructure/buildings, (2) waste from construction of civil infrastructure/buildings, (3) soil, rocks and vegetation due to excavation land levelling, as well as civil works, and (4) waste arising due to road maintenance activities (Kourmpanis et al. 2008; EPA 1995). The waste materials include materials used in the construction, containers of materials used for construction, bricks, tiles, plaster, sand, waste oils, grease, batteries, pieces of sanitary ware, metals, colors, fluorescent bulbs, soil, pieces of concrete, plastic pipes, resins, wires, insulating materials, overlay plates, gravel, ceramics, coats, stones, and glues. EU generates nearly 850 million tonnes per year of C&D waste which represents 31 % of the all waste generated in the EU

(Christian and Mads 2009). Total C&D in 2008 in England was estimated as 86.9 million tonnes (DEFRA, 2012). About 170 million tons of C&D materials were generated in 2003 due to building related activities in the U.S (EPA 2003).

Most of the construction waste is used within the site for filling lower areas. But when the waste exceeds the site capacity it needs to be hauled to other site of land fill site. Even though the waste can be reused as done in disaster areas, the builders prefer to use new products in order to achieve pre set quality determined by architects, structural engineers.

9.4 Service Industries

Service industry mainly includes activities which does not convert raw material to finished products. With the small exception like cooking in hospitality the activity will bring in finished ready to use items.

9.4.1 Entertainment

Entertainment includes sports activities with spectators, theatre, movies, amusement park, magic shows etc. These activities generate packaging materials used for ready to eat food and drinks. The other waste comprises of handout, hoardings, disposable plates and cups, aero shows, live concerts, fruit and vegetable peel, used tickets, etc. The quantity of waste depends on the magnitude of the show. It is not surprising to see slippers, torn dress materials in some entertainments as they involve stampede.

9.4.2 Hospitality

Hospitality industry mainly comprises of hotel, motels, and resorts. The major solid waste generated in this sector comprises of paper and food waste. The food waste is often used for animal feed or composting. In smaller motels the degradable waste is just dumped in heap or pit and allowed for a year for degradation and stabilization before it is used for farming/gardening activity.

9.4.3 Software

The major activity in software is providing software and support to other business needs. The industry used computers (Fig. 9.17), computer consumables, printers and other electronic hardware and office stationary. The major waste components

Fig. 9.17 Computers and printers being loaded for transportation

include WEEE and office stationary. Huge software park will also have cafeteria resulting in substantial amount of food waste. The generation of hazardous waste like used oil from diesel generators and lead batteries cannot be ruled out.

9.4.4 Communication

Communication industry includes mass, group and individual communications. Examples of mass communication include (1) radio, (2) television, (3) print media, and (4) internet. Examples of group/individual communication include (1) postal communication, (2) telecom, and (3) email. With advances in technology a single instrument can be used for mass as well as group/individual communication. With wireless technology catching up fast communication through wires and cables are disappearing so as the waste associated. The telecommunication involves interconnection of a series of electronic equipments and an energy supply. The major waste associated with telecommunication would be WEEE and office stationary. The major waste associated with the print media would be paper soiled with ink and packaging waste.

9.5 Commercial Activity

Commercial activity varies with industry in the aspect of absence of mass production of material and services. The major commercial activities are restaurants, offices, shops and wherehouses.

9.5.1 Restaurants

The major raw material to restaurant originates from agriculture, fishing and manufacturing sector. Unlined food industry which manufactures food anticipating the customers, most of the time restaurant prepare after confirming customer. While the products of food industry are transported and distributed through network of traders, restaurants will cater for the food at restaurants or at the location determined by customer. The waste from the restaurant is dominantly degradable in nature and can be used as animal feeds. The non degradable fraction of food waste comprises of disposable cutleries, cups, plates, packaging material etc.

9.5.2 Offices

The majority of solid waste generated in this sector comprises of paper and food wastes. Major constrains and considerations in offices are lack of available space, security concerns for confidential documents and separation of recyclables (Matthew 2009). After corrugated cardboard and newspapers office paper is the third major fraction of paper waste 7.3 million tons in 1988. In 1990, nearly two million tons of paper in the USA went through photocopiers contributing to 25 % of entire office paper use (Robert and Bette 1991).

9.5.3 Shops

The shops may be for retailing or wholesale. The quality and quantity of waste generated depends on the goods sold and magnitude of the business. The major waste comprises of expired goods, packaging materials and damaged goods. While sometimes expired goods are taken back by distributor or manufacture damaged goods have to be disposed at the cost of shop owner/management.

Retail operations generate two major types of solid waste: food and packaging wastes. In 1995, 48.2 million tons of food was wasted by foodservice operators, food retailers, and consumers out of which 2.7 million tons of food were wised at the retail shops. In 1993 retail industry produced 25.4 million tons of packaging material used for grocery which was greater than one-third of the overall containers and packaging material in the MSW waste stream (Franklin Associates 1995; Terry and David 2000).

9.5.4 Where Houses

Where houses store large quantity of goods prior to distribution and the materials stored includes agricultural output or manufactured goods at an industry. The waste may not be generated every day and the quantity depends of value of material and precautions taken to protect the goods.

9.6 Source Reduction

Source reduction is the lessening of materials entering into the system whether it is manufacturing facility or a city or any other establishment. The innovation in electronics has resulted in decrease size of electronics goods, thus resulting in less waste generation. The advance in metallurgy and material science has also resulted in material of high strength thus reducing the material required for manufacturing vehicles and machineries.

The key principles of source reduction practiced by industries are: (1) use of recyclable packaging material, (2) locate the source of product/byproduct wastages and take corrective action, (3) innovate and change process, (4) create awareness among employees, transporters as well as raw material suppliers, and (5) find alternate use and market for the waste.

The examples include recyclable packaging material in the case of automobile industry wherein components are packed in recyclable packaging material. Identifying the source of product/byproduct wastages can be often minimized in food industry and chemical industry by proper storage of raw material and control of intermediate steps. The potato chips industry which uses huge amounts of potatoes in India often uses loose raw materials in farm itself. Many potato growers store potatoes at field by providing temporary sheds which can be avoided by creating proper infrastructure for storage. The potatoes damaged during digging are often sorted for selling in nearby towns which is often picked by restaurants for lower price. Any delay in sorting damaged and rotten potatoes would lead to further loss of potatoes as good potatoes will also be attacked by microbes responsible for purification.

The mangoes are often plucked from trees when they are sufficiently matured but not fully ripe to avoid damage during transportation/storage as ripe fruits will be damaged in heaps due to contact with rotten fruits as well as weight of fruits above ripe fruit placed in lower level of heap. Any delay in processing of fruits while preparing fruit pulp would lead to loss of raw material.

9.7 Zero Waste: Concept and Practice

Zero waste is a philosophy which encourages reuse of a product so that the disposal will become minimal. The principles of zero waste are: (1) flow of resources shall be cycle with minimum input and output, (2) extended producers responsibility to bring back the waste into remanufacturing system, (3) optimize productive use of resources, and (4) stress on use of non-toxic materials. 'Convert waste into a resource' is the essence and concept of the zero waste. In reality it can be achieved in many ways. Within the defined boundary the zero waste can be achieved by reduce, recycle, recovery, and reuse. The defined boundary can be house, institution, industry, community, city or country. Within the industry zero waste concepts can be achieved by converting waste into value added product or by product so that anything leaving the industrial boundary will fetch an economic value. The Australian Government has formed South Australia's Waste Strategy 2011–2015 wherein it will regulate to support an industry-led method for collecting and recycling computers as well as televisions (Zero Waste SA 2011). Food waste in the UK has reduced by 13 % per year since past three years (WMW 2011a, b).

The practice will be easy if the one of the material generated had ready demand. Considering the example of thermal power plant, entrepreneurs will not operate thermal power plant for generating ash. But if the ash can be sold at a value then both entrepreneur and community will be benefitted. The useless fly ash which posed great concern two decades back has been totally nullified as it can be used as raw material in cement. The buyer of fly ash for manufacturing cement will benefit as he can avoid the mining and transportation of limestone which is a limited resource.

9.8 Innovative Technologies

Groundwater pollution due to seepage of contaminants from waste dump site or rupture of liners in landfill sites is a major challenge. Permeable reactive barriers (PRBs) have been identified as promising technology during the last decade to curb groundwater contamination due to seepage of pollutants through subsurface strata. Even though PRBs have been tried out in many developed countries, such facilities are not used extensively in many developing countries due to limitations associated with pump-and–treat technologies.

In PRBs, reactive material is placed across a plume of contaminated water is moving or likely to move creating a passive treatment system. The contaminated liquid plume enters the barrier and treated water will come out on other side of the barrier (Fig. 9.18). Iron metal is used as the reactive media in most of the PRBs for decontamination of contaminants as Iron metal is capable of reducing dehalogenate hydrocarbons, and precipitate anions and oxyanions. Some installation use organic materials as reactive media in PRBs to biologically remediate contaminants, like nitrate and sulphate.

As on date commercial PRBs are built in following configurations: (1) funnel and gate, and (2) the continuous PRB. The depths of currently installed PRBs measure about 15–20 m below ground level. In funnel-and-gate PRBs impermeable walls like sheet pilings, slurry walls, etc. are used to direct the contaminant plume to reactive media. On the other hand continuous PRB transects the plume flow path. The PRBs are a great way to reuse solid wastes in another way.

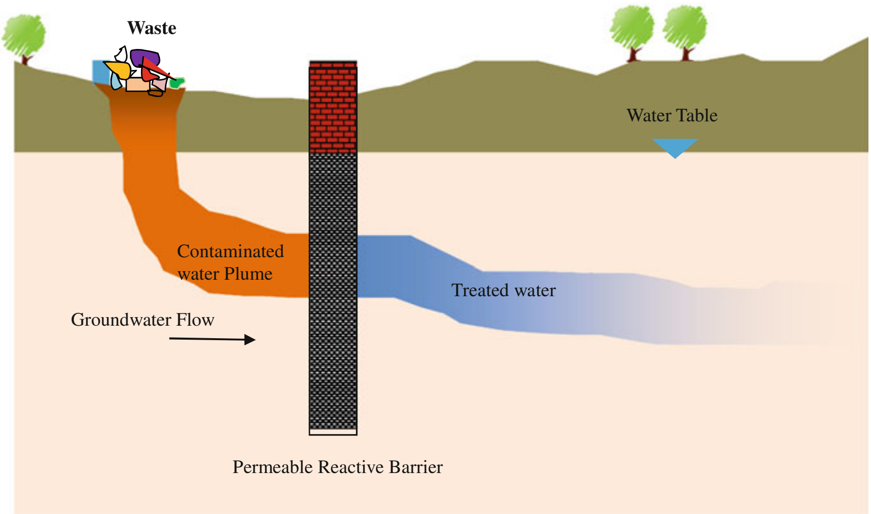

Fig. 9.18 Schematic diagram of permeable reactive barrier

Bottom ash from thermal treatment of waste accounts for 20–25 % of waste burnt. Approximately about 16 million tones of bottom ash are generated due to combustion of around 70 million tonnes of in Europe during 2009. Currently WTE plants extract metals form bottom ash and other materials are used as aggregate in road as well as building construction. Netherlands extracted 21,900 tonnes of nonferrous metals and 119,000 tones of ferrous metals form bottom ash in 2009.

Plasma arc gasification and microwave plasma gasification are relatively new technology with respect to waste to energy. Plasma arc gasification involves combustion of waste at 4,000–7,000 °C using an electric arc whereas the new technology called microwave plasma gasification involves use of microwave radiation through patented plasmatron to wherein waste is heated to form cloud of plasma. Heated water vapor is added to the plasma to from syngas and slag.

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Chapter 10
Radio Active Waste

Radioactive waste is the material that is contaminated with radionuclides at activities or concentrations higher than the clearance levels established by individual countries for which no use is anticipated. All activities that produce/use radioactive materials generate radioactive wastes which include mining, nuclear power plant, processes in industry, defense, medicine, and research. Radioactive waste is generated in gas, liquid or solid form. Radioactivity can remain for a few hours to thousands of years. Depending on the type of waste, the disposal facility needs to be contained for a very long time ensuring health and safety of the people and quality of environment.

From the late 1940s to early 1970s radioactive wastes were either dumped at sea or accumulated at nuclear sites. From the mid 1970s to the early 1990s, the international nuclear industry had a series of setbacks in terms of high expenses and technological problems. Accidents at three Mile Island and Chernobyl added to the decline in confidence and trust in the nuclear industry (CORWM 2006). There was little public concern over radioactive waste during the initial stages of the nuclear industry. But over time, a number of organizations have voiced their concerns.

The quantity of radioactive wastes generated varies from nation to nation depending on the scale and range of nuclear and radioactive material used. Between 1970s and 1980s, more than 30 % of the uranium generated in the USSR was from the Central Asian republics. 456 nuclear tests were done by the USSR between 1949 and 1989 on the Semipalatinsk testing ground in Kazakhstan. Even though the mining activity ceased from 1961 to 1995 at most of the mines, restoration works were done only at a few facilities. Approximately 800 million tonnes of radioactive waste are awaiting safe disposal in Central Asia (Zhunussova 2011).

All the IAEA's member states generate radioactive wastes. In 1988, nuclear power supplied around 7 % of the world's developing countries and seven developing nations in Asia, Latin America, and Mediterranean region had 24 nuclear power plants (Thomas et al. 1989). In 2002, around 20 % of the United States as well as 17 % of world's electricity was generated from nuclear energy.

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As per MIT (2009a, b) there were about 44 nuclear power plants under construction across the world in 12 countries. Considering the full nuclear fuel cycle in addition to reactors, radioactive waste is generated in uranium mines, mills, enrichment facilities, spent fuel repositories, as well as decommissioning sites.

As per IAEA (1995), the principles of radioactive waste management are: (1) protection of human health, (2) protection of the environment, (3) protection beyond national borders, (4) protection of future generations, (5) burdens on future generations, (6) national legal framework, (7) control of radioactive waste generation, (8) radioactive waste generation and management interdependencies, and (9) safety of facilities.

10.1 Significance

Radioactive materials/wastes are potentially harmful as they emit ionizing radiation, which will damage cells in the body and high doses can cause deaths within a short time. Low doses over extended periods can induce cancer. Some nuclear materials are highly toxic too. Some radioactive materials like plutonium can start nuclear chain reaction if not managed properly.

Due to the significant danger and risk associated with use of radioactive material without precaution, many legislations have been formulated all over the world. Some of these legislations which deal with radioactive materials are given in Table 10.1.

Radioactive waste generally occurs in the following places (US EPA, NA): (1) spent nuclear fuelreprocessing of spent nuclear fuel, (2) transuranic waste, (3) mining and milling of uranium, (4) low-level waste from research and medicine, (5) naturally occurring radioactive materials. Three main sources from which nuclear waste arises are: (1) the nuclear fuel cycle (NFC) used for military uses and power generation, (2) non-NFC institutes (medical and research institutions, non-nuclear industries), and (3) accidents. Most of the radioactive waste is generated in nuclear plants in the NFC (Fig. 10.1). The nuclear fuel cycle is an array of processes followed for generation of electricity in nuclear power reactors from uranium. The nuclear fuel cycle begins with the uranium mining and concludes with the nuclear waste disposal with an option of reprocessing the used fuel.

As well known, uranium is a slightly radioactive metal which occurs naturally in the Earth's crust. In some parts of the earth, the concentration of uranium is sufficiently high making it economically feasible for extraction. Uranium is excavated by underground or open pit mining. Most of the world's uranium comes from in situ leach (ISL) mining. In ISL oxygenated groundwater is circulated through porous ores to dissolve the uranium oxide. The uranium oxide is later recovered from the solution. The original ore contains about 0.1 % uranium.

Milling is usually carried out near uranium mine for extracting the uranium from the ore. Milling generates uranium oxide concentrate sometimes referred to as 'yellow cake' and it comprises more than 80 % uranium. In a mill, crushed and

Table 10.1 Some of the legislation dealing with radioactive waste throughout the world

Country	Legislation
China	Measures on the management of urban radioactive wastes
Sri Lanka	Radioactive minerals act
Kazakhstan	Law no. 93-1 on use of nuclear energy
Pakistan	Pakistan nuclear safety and radiation protection ordinance
Philippines	Toxic substances and hazardous and nuclear wastes control act
Australia	Atomic energy act
	Australian radiation protection and nuclear safety act
	Australian nuclear science and technology organisation act
	Nuclear non-proliferation (safeguards) act
Austria	Atomic liability act
	Federal constitutional act for a nonnuclear Austria
Canada	Nuclear safety and control act
	Canadian environmental assessment act
	Nuclear liability act
Czech Republic	Act on the peaceful uses of nuclear energy and ionising radiation
Finland	Finnish nuclear energy act
France	Act on transparency and security in the nuclear field
Germany	Act on the peaceful utilisation of atomic energy and the protection against its hazards
Hungary	Atomic energy act

ground-up ore is leached with strong acid or alkaline solution from which uranium oxide precipitated. Remainder of the ore becomes tailings which are emplaced in engineered facilities. Tailings contain long-lived radioactive substance in low concentrations and heavy metals.

Nuclear waste in storage casts takes approximately 10,000 years before it reaches radiation which will be safe for human exposure. As per Benjamin (2011) the lowest estimate available for the storing one tonne of nuclear waste will be US$35,000 per year (Benjamin 2011).

Many countries have relatively small quantities of ILW and HLW hence studies have been supported by the European Union, to check the viability of a regional repository wherein the waste from many countries could be placed (IAEA 2005). More than 100 near surface type repositories exists in the world (IAEA 2005).

The uranium oxide from uranium mill cannot be directly used as fuel for a nuclear reactor. Only 0.7 % of natural uranium is capable of undergoing fission. The capability of a material for undergoing fission is called fissile. The form which is capable for undergoing fission is the uranium-235 (U-235) isotope and uranium-238 (U-238). The concentration of the fissile uranium-235 isotope is usually kept between 3.5 % and 5 % U-235 by enrichment process which requires the uranium in a gaseous form. Hence, the uranium oxide concentrate is first converted to uranium hexafluoride as it is a gas at low temperatures.

The uranium oxide is refined to uranium dioxide and then converted into uranium hexafluoride. The uranium hexafluoride is drained into 14-tonne cylinders in

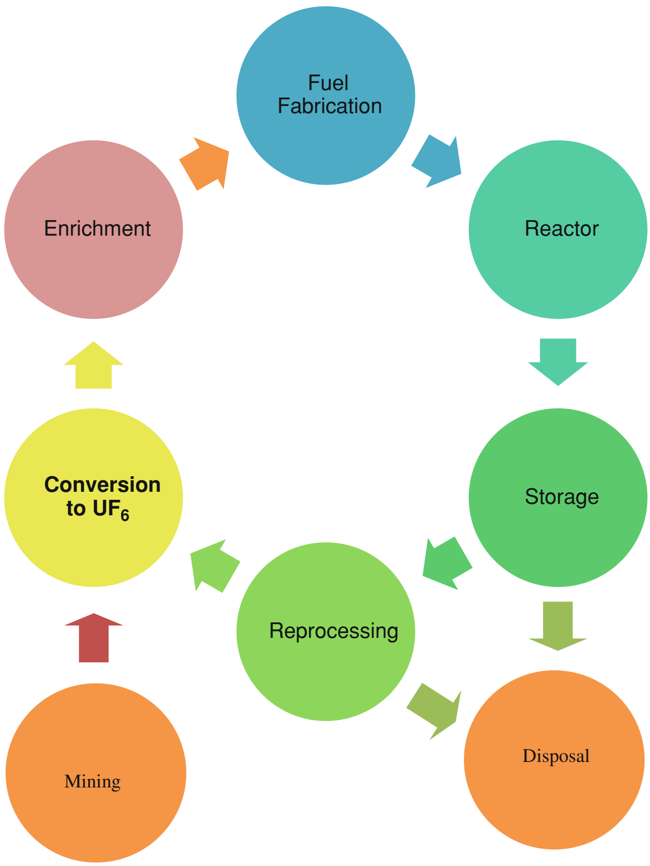


Fig. 10.1 Nuclear fuel cycle

which it solidifies. These metal containers are shipped to enrichment plants where they are separated into two streams: (1) low-enriched uranium, and (2) depleted uranium. Depleted uranium is depleted in U-235 and called 'tails'.

Approximately 10,000 tonnes of spent nuclear fuel is disposed every year as nuclear waste (Benjamin 2011). As only 15 % can be reprocessed nearly all of the fuel used in nuclear power plant will be converted to waste (Benjamin 2011). On an average every plant will generate 30 tonnes of waste a year which will be radioactive for nearly 250, 000 years (Benjamin 2011).

The quantities of radioactive waste increased after the Second World War (CORWM 2006). The total quantity of uranium produced till the year 2004 all over the world is about 2.2 million tonnes with each of the US and Canada producing nearly 1/6th of the world total (ONEA 2006). During the years 2002–2004, Australia generated approximately 20 % of world's total and Canada generated about 30 % of world's total uranium (ONEA 2006). The total extent of tailings accumulated in Australia in 1996 was nearly 50 million tonnes

(IAEA 2007). The total commercial mill tailing, generated in the USA till the end of 1996 was about 190 million tonnes (US DoE 1997). As per the estimations made by Makhijani et al. (1995), warheads produced nearly 34 million tonnes each of mine and mill tailing. The European Union generates nearly 35 % of its electricity from nuclear energy (European Commission 2004). The total nuclear waste from Uranium mining and milling is estimated to be around 4.1 million tonnes (Ramana et al. 2001).

Reactor fuel usually will be in the form of ceramic pellets formed from pressed uranium oxide sintered (baked) at a temperature of over 1,400 °C. These pellets are encased in metal tubes and arranged into a fuel assembly. The nuclei of U-235 atoms split inside a nuclear reactor and release energy which is used to convert water into steam which is used to drive a turbine connected to generator for production of electricity.

With time the quantity of fission fragments formed in the fuel will increase where they can be used as fuel and hence removed from the reactor. Used fuel is either reprocessed or shall be disposed. Solid waste is generated by during treatment of liquid waste by chemical precipitation, ion exchange, ultra filtration (Fig. 10.2), reverse osmosis (Fig. 10.3) and evaporation (Fig. 10.4).

10.2 Classification of Waste

Classifications are derived from different perspectives like safety, physical/chemical properties of the waste, or regulatory issues (IAEA 1970, 1999). Classification of radioactive waste varies from country to country.

The key factors in any classification are the half-lives and radionuclide concentrations (Ojovan and Lee 2005). Radioactive waste is usually classified by the activity level as: (1) exempt waste, (2) low-level waste (LLW), (3) intermediate-level waste (ILW) and (4) high-level waste (HLW). The abbreviation LILW is used to mean low and intermediate level wastes.

Exempt waste has activity levels below the exemption levels and is excluded from regulatory control since the radiological hazards are negligible.

LLW has activity levels more than clearance levels but do not need shielding while handling or storage. The major components of LLW comprise of: (1) metals from of redundant equipment, (2) metals from decommissioned ducting, piping and reinforcement, (2) organic materials form of discarded protective clothing, towels and plastic wrappings, and (3) concrete, cement and rubble from decommissioning. LLW is generated from hospitals, industry and nuclear fuel cycles. In order to reduce its volume, it is usually compacted or incinerated prior to disposal (Nirdosh 1999). LLWs are disposed of by shallow land disposal methods wherein LLW is compacted and packaged in big metal containers and placed in an engineered vault below the surface.

Fig. 10.2 Ultrafiltration plant

Fig. 10.3 Reverse osmosis plant

Fig. 10.4 Forced evaporation plant

Some countries further classify LLW with very low activity as very low-level waste (VLLW). VLLW from uranium mill tailings is a byproduct material from the processing of uranium bearing ores (Sutherland et al. 1982).

ILW contains activity levels higher than LLW and less radioactive than HLW. It requires shielding while handling or storage. ILW includes resins, chemical sludge, metal reactor fuel cladding, and contaminated materials (Raj et al. 2006). In some cases it also requires shielding. ILW is the waste having radioactivity levels more than the upper limits for LLW, but it does not require heating to be considered while designing storage or disposal facilities. Metals are the major component of operations. The ILW largely comprises of (1) fuel shell and fuel element from dismantling and reprocessing of used nuclear fuel, (2) scrap items from operations and maintenance of radioactive plant, (3) flocks generated during treatment of radioactive liquids and sludges, (4) graphite from reactor cores, and (5) decommissioning metals.

The ILW waste does not generate significant amount of heat, but can require shielding. Some of the ILW can also have very long half-life. ILWs include items like nuclear fuel shell and reactor components, graphite from reactor cores, sludges that arise during treating radioactive liquid effluents, and some wastes from medical/industrial users. ILW is stored in tanks/vaults/drums with some shielding to safeguard operators from radiation. Waste generated during rector de commissioning is termed as reactor decommissioning waste (RDW). Some of the ILW generated during reactor decommissioning is short lived with half year life less than 30 years.

HLW has significantly high activity levels and needs comprehensive personnel protection, shielding and remote handling. Usually this waste is the spent fuel itself or arises during spent nuclear fuel reprocessing.

Low and intermediate level wastes-short lived (LILW-SL) comprises of waste with long lived alpha emitting radionuclides up to 4,000 Bq/g in individual waste packages and to an on the whole average of 400 Bq/g per waste package. Low and intermediate level wastes-long lived (LILW-LL) comprises of waste with long lived radionuclide concentrations more than limitations for short lived waste.

Short-lived waste contains radionuclides with half-lives less than that of 137Cs, i.e. 30.2 years. Long-lived waste contains radionuclides with half-lives greater than 30.2 years. Long-lived low level waste type arises from: (1) industrial processes (like the uranium processing industry, the gas and oil industry, the phosphate industry), and (2) from the cleanup of sites contaminated with radium. This type of waste typically contains low levels radionuclide contaminants. This type of waste occurs in large volumes and near surface disposal facilities (NSDF) are not appropriate for this waste type. Deep disposal is considered to be too costly. Furthermore, national regulations vary and some countries consider them as radioactive waste while some other nations consider them as chemical wastes and still others do not regulate such wastes.

NFC generates all kinds of radioactive wastes. NFC is further defined as open NFC and closed NFC. In closed NFC, spent nuclear fuel will be reprocessed to extract fissile U and Pu whereas in the open NFC, spent nuclear fuel will be disposed without reprocessing.

Naturally occurring radioactive materials (NORM) contain radionuclides found in the nature. Naturally occurring radioactive waste can be of two types: discrete and diffuse. Discrete NORM, such as a radium source used during medical procedures has a relatively high radioactivity in a very small volume. Diffuse NORM has a lower concentration of radioactivity with high volume of waste.

Nuclear reactors consist of pellets made up of ceramic uranium dioxide sealed in hundreds of metal rods which are bundled together to form "fuel assembly." When most of the usable uranium has been fissioned in the process of generating electricity, the "spent" fuel assembly is removed and stored in water pools in the reactor site for removal of leftover heat in spent fuel. Spent fuel is reprocessed for recovering un-fissioned uranium and plutonium. In this process the fuel is dissolved by strong chemicals, resulting in liquid high level radioactive waste (HLW).

HLW contains fission products as well as transuranic elements produced in the reactor core (Liu et al. 2007; Ahn et al. 2007; Peters et al. 2006). HLW comprises mainly fission products and generates a large amount of heat. HLW arises as a liquid form during reprocessing of spent nuclear fuel for separation of uranium and plutonium. These liquid wastes are converted to solid forms by a process called vitrification, stored for more than 50 years to let the radionuclides decay to levels suitable for long-term management. In vitrification high-level waste is calcined to evaporate the water from waste and assist the stability of the glass generated (Min et al. 2007; Sobolev et al. 2005; Sheng et al. 2001; Park and Song 1998). Some HLW may remain for thousands of years.

Transuranic waste (TRUW)s are wastes contaminated with alpha emitting transuranic radionuclides whose half-lives are greater than 20 years and concentrations greater than 100 nCi/g (3.7 MBq/kg), excluding HLW (Silva 1992). TRUW originates from nuclear weapons production. "Transuranic" refers to the atoms which have atomic number greater than uranium (e.g., plutonium). The TRUWs consist of items like rags, tools, contaminated cases and equipments contaminated with radioactive materials. Some TRUW waste emits high penetrating radiation and hence requires protective shielding. Some TRUW waste does not emit high penetrating radiation but is dangerous to health when particles of it are inhaled/ingested as it damages lung and other internal organs.

The nuclear waste management (NWM) methodology involves a short-term management wherein the waste is treated immediately and, a long-term management wherein the waste is stored, disposed or transformed into a non-toxic form (Grill 2005; Horsley and Hallington 2005; Fritschi 2005).

Uranium mill tailings are remains after uranium is extracted from the uranium ore. Tailings are placed in piles close to the mills meant for extraction. Radium, selenium, molybdenum, uranium, and thorium are the important radioactive components in uranium mill tailings. Radium decays to produce radon.

Accelerator-produced radioactive waste is generated during the functioning of atomic particle accelerators for research, medical, or industrial use. The accelerators use magnetic fields for moving atomic particles. The radioactivity in the waste from accelerators is short-lived and will be less than 1 year. The waste can be stored at production facilities until the waste is no longer radioactive. An extremely

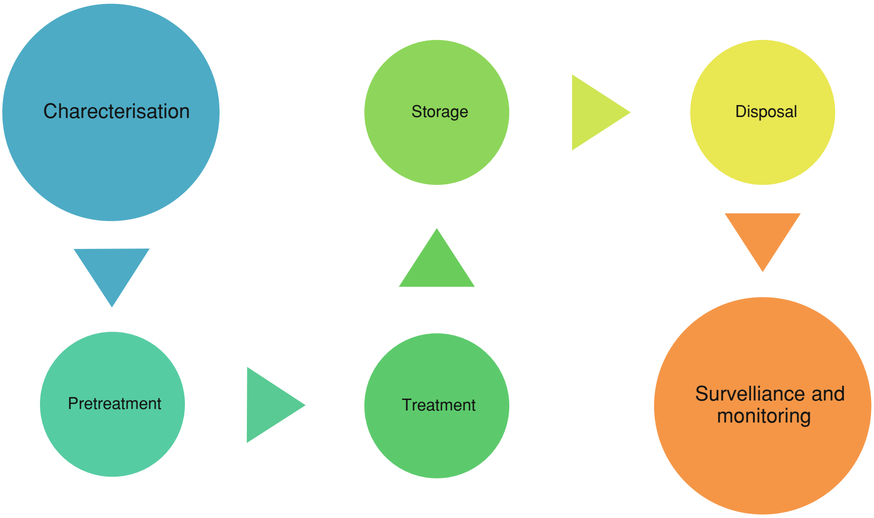


Fig. 10.5 Stages of managing radioactive waste

minute fraction of the waste may have half lives more than 1 year. The exempted waste comprises of waste wherein the activity levels are at or below a clearance level. The clearance levels are determined based on an annual dose to members of the public of less than 0.01 mSv.

Solid wastes are categorized based on the radiation type, field, and concentration of radioactivity. Solid waste can be categorized as combustible or non-combustible and compressible or non-compressible. Specially designed incinerators are used for burning the combustible solid radioactive wastes. Volume reduction of compressible waste is attained by hydraulically operated baling. The compactable waste can be further pelletized using hydraulic press.

10.3 Characterisation

The waste is characterized based on the physical, chemical and radiological properties for the purpose of management. The important stages of managing radioactive waste (Fig. 10.5) include waste characterization, pre-treatment, treatment, storage, disposal, surveillance/monitoring. Figure 10.6 shows schematic diagram of waste processing and disposal routes in a nuclear facility.

The storage of radioactive waste is carried out to ensure isolation, environmental protection and monitoring. Spent fuel removed from the reactor is stored under water to suppress heat being generated and to limit the radiation levels. After several years when the heat produced by the decay of the radioactive waste decreases it is stored in an above ground storage facility with air-cooling.

10.4 Pre-Treatment

Treatment of radioactive waste is usually preceded by pre-treatment. Pre-treatment is the operations preceding the waste treatment and comprises of collection, segregation, adjustment and decontamination. It is performed to: (1) facilitate treatment, transport, packaging and conditioning, (2) segregate into active and non-active streams, (3) to recover products for recycling. Pre-treatment of waste consists of collection, segregation, interim storage, chemical adjustment as well as decontamination. Pre-treatment helps to improve safety, lower radiation exposure and reduce waste management costs.

Common adjustment procedures are: (1) chemical adjustment, (2) removal of components which are no compatible with material used during treatment, (3) destruction of unwanted components, (4) modifying the behaviour with alkaline earth ions, (5) electrolytic destruction of organic acids, and (6) evaporation.

Size reduction is done to facilitate reduce packaging for transportation costs and facilitate subsequent treatment. Chemical adjustment is done to correct the waste characteristics to fit the requirements of succeeding storage, treatment or immobilization processes.

10.4.1 Packaging

Packaging of solid radioactive waste is an important pre-treatment operation carried out for easy handling, transportation and further processing. It has to fulfil with transport regulations and safety standards.

Non-combustible LILWs are normally collected as compressible as well as non-compressible materials in metal/cardboard boxes of 20–50 L or metal drums of 100–200 L depending on the volume of waste generated. Combustible LLW is usually collected at the generation point in transparent plastic bags with thickness between 0.1 and 0.2 mm. Such bags will be marked with radiation symbol and will usually have volumes of 15–50 L. The plastic bags are closed with adhesive tapes.

10.4.2 Decontamination

Decontamination is a pretreatment done for contaminated part of material/structure with a decontaminating agent so that it can be reused or disposed as non-radioactive waste. Decontamination of spent tools and instruments are done with the objective of reuse.

Normal decontaminating agents used are: detergents, dilute acids, organic solvents, chromic acid solution, CCl_4, kerosene, oxalic acid, NH_4OH, HCl, ammonium citrate, ammonium citrate, dilute mineral acids concentrated nitric acid, mineral acids, trisodium phosphate, dilute nitric acid, sodium citrate, ammonium bifluoride, abrasion.

Decontamination is the removal of contamination from the surfaces of facilities/equipment. Characterization helps to understand physical, chemical and radiological characteristics. Decontamination can be carried out by washing, heating, mechanical cleaning, chemical or electrochemical action, or other techniques. The objectives of decontamination are (IAEA 2001): (1) reduction of radiation exposure, (2) salvage equipment and materials, (3) reduce the volume of equipment, (4) restore the site and facility, (5) remove loose radioactive contaminants, and (6) reduce the magnitude of the residual radioactive source. Decontamination activity must consider: (1) safety, (2) efficiency, (3) cost effectiveness, (4) waste minimization, and (5) feasibility of industrialization.

Chemical decontamination is carried out by circulating the appropriate chemical in the system or by immersing parts in chemicals, which must then be agitated. Mild chemical decontaminants like detergent, foam, cream dilute acids/alkalis are used for decontamination of large flat pieces on site, doors, pools, and reactor containments. Use of mild chemicals can only remove loose contamination and generates high secondary waste. Aggressive chemicals like strong acids/alkalis and oxidizing/reducing agents are used for removing thin layer of metals from the surface.

Electrochemical decontamination (electropolishing) is widely used in non-nuclear industrial applications to generate a smooth polished surface on metals/alloys. In this process metal layers are removed from a surface.

Mechanical decontamination includes as surface cleaning (e.g. sweeping, scrubbing) and surface removal (e.g. grit blasting, drilling and grit blasting). This method can be used as an alternatively/simultaneously/sequentially with chemical decontamination.

Decontamination by melting completely destroys contaminated object and technique is effective if contaminants are volatile or in the slag or dross (e.g. plutonium). Melting is done in foundries and ingots are stored if necessary till the radio activity reaches safe limits.

Decontamination techniques include flushing with water, strippable coatings, dusting, vacuuming, wiping, scrubbing, high pressure liquid nitrogen blasting, steam cleaning, abrasive cleaning, sponge blasting, high pressure and ultra-high pressure water jet, CO_2 blasting, Freon jetting, wet ice blasting, grinding, shaving, scarifying, milling, grouting, chipping, electrochemical polishing, thermo chemical decontamination.

10.5 Treatment

Treatment of radioactive waste is done to achieve the following main objectives: (1) volume reduction, (2) removal of radionuclides, (3) change of chemical composition and physical state. The usual methods adapted to in treatment of radioactive waste is discussed in subsequent sections.

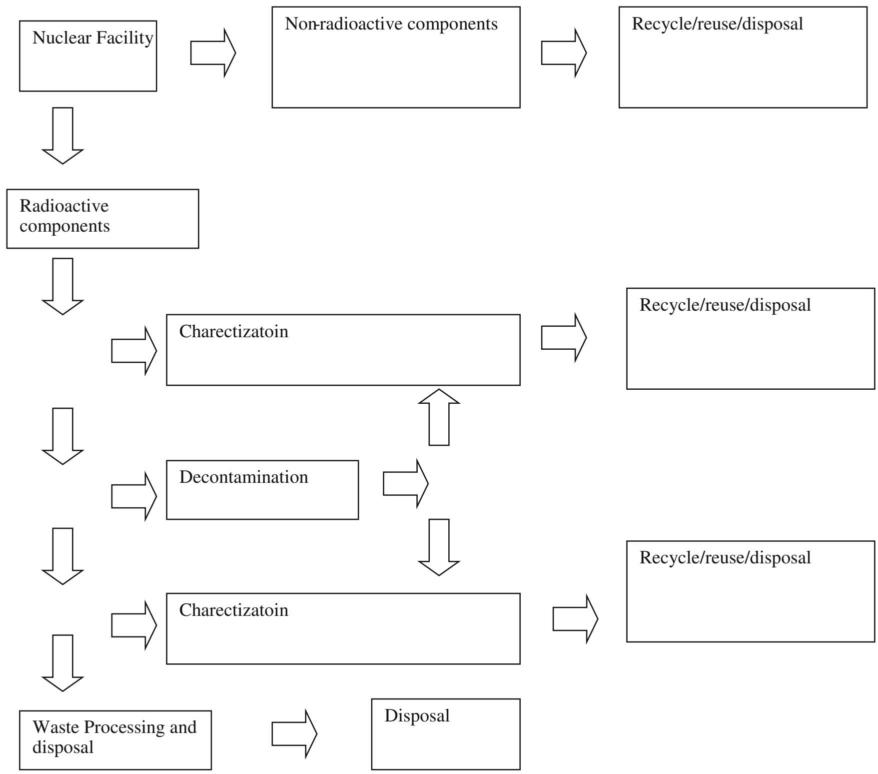


Fig. 10.6 Schematic diagram of waste processing and disposal routes in a nuclear facility

10.5.1 Compaction and Super-Compaction

In compaction, solid waste is compressed into boxes or containers to reduce the volume with volume reduction factor (VRF) of 2–5. Super-compactors are used to achieve VRFs of about 100.

10.5.2 Incineration

Combustible radioactive waste is burnt in specially designed incinerators. The incineration generates ash, soot and condensate from the off-gas pollution control systems. Usual VRF achieved in the incineration is 500–1000 in case of liquid waste and 50–100 for solid radioactive waste. Ash contains about 90–95 % radionuclides whereas soot contains about 1–5 % and the condensate contains about 0.1–2 %. The radionuclide content in waste incinerated is generally limited to an alpha activity of 10^{-5} Ci/kg and beta activity of 10^{-4} Ci/kg (Ojovan and Lee

2005). The temperature in the combustion chamber is about 900–950 °C and higher temperature is maintained in the post-combustion chamber. Shaft furnaces with plasma burners are efficient and can be used for both organic and inorganic wastes like glass, ceramics, and construction materials without pre-treatment. Temperatures of 1,400–1,600 °C can be achieved with plasmatrons (plasma burners) which melt the ash residues.

10.5.3 Chemical and Thermochemical Decomposition

Chemical decomposition is done by digestion of organics with acid. In thermochemical decomposition waste are incinerated using powder metal fuels (PMFs) to provide simultaneous decomposition of organic matter and, confine hazardous radioactive and chemical substance in residue.

10.5.4 Partitioning and Transmutation

The key objective of partitioning and transmutation (P&T) activities is to remove or reduce the quantity of long lived radio nuclides from radioactive waste. P&T will not totally remove all long lived radio wastes. The complex processes will give a certain quantity of nuclear waste with long-lived radio nuclides reduced with a factor of hundred or more. Hence, the time required to reduce the radiotoxicity to the level of natural uranium can be 2 years instead of 200 years. The transmutation of the nuclides is achieved by irradiation with neutrons. Since the process releases a huge amount of energy it must be cooled. Transmutation is preceded by partitioning wherein the long-lived radionuclide from the radioactive waste is separated. Success of transmutation depends on partitioning as the impurities can absorb neutrons.

10.5.5 Conditioning

Conditioning is the operation to produce a waste package appropriate for handling, storage, transportation and disposal. Conditioning is an engineering process with large entities packages.

The conditioning of intermediate level radioactive liquid waste is carried out depending on the following: (1) compatibility of matrix and waste, (2) mechanical and chemical durability of solidified products, (3) cost of processing, (4) throughput, and (5) disposal options. Immobilization of spent ion exchange resins is done with a polymer matrix.

The conditioning of radioactive waste includes operations that change radioactive waste into solid form appropriate for handling, storage, transportation and disposal. This conditioning comprises of (1) immobilization of radioactive waste, (2) placing the waste into containers, (3) providing additional packaging if necessary.

Most common immobilization methods are solidification of ILW and LLW in cement or polymer and vitrification of high-level liquid waste. Immobilized waste may be packed in containers varying from 200 L steel drum to thick-walled containers, based on the nature and concentrations of radionuclides.

10.5.6 Immobilization

Immobilisation reduces the possible migration or dispersion of contaminants. It is the alteration of radioactive waste into a waste-form by solidification and encapsulation for facilitating handling, transportation, storage and disposal. Solidification is achieved by chemical incorporation of waste into structure of a matrix. Encapsulation is achieved by physically surrounding waste by material like bitumen or cement in order to retain and isolate radionuclides.

Radioactive wastes are immobilised in a range of matrices for storage or geological disposal. Commonly used materials include borosilicate glass, and bitumen.

The immobilisation of matrix is elected depending on: (1) nature of the waste, (2) properties of the matrix, (3) secondary effects of immobilization, (4) intended storage/disposal route, (5) costs associated, and (6) safety.

The immobilisation of wastes is planned to prevent/restrict the unintentional dispersion of radionuclides into the environment.

Waste containment involves packaging in separate units to make easy handling, transport and inspection.

Immobilisation of radioactive ensures that they are safe from the following: (1) stored energy is minimized, (2) the waste will attain low reactivity, solubility and flammability, (3) the waste is resistant to corrosion, reaction or microbial action, (4) the waste can be cooled by natural air circulation.

High-level liquid waste is concentrated by evaporation prior to storage in stainless steel tanks. This type of waste is managed by immobilization followed by interim retrievable storage and deep geological disposal. Slurry of preconcentrated waste and glass forming substance is transferred to process vessel in a multi-zone furnace made of high Ni–Cr alloy. The calcinated the molten mass is drained into stainless steel canisters and allowed to cool slowly. Ceramic melter has advantage of higher throughput due to better product durability and continuous operation on account of greater achievable processing temperature.

10.5.6.1 Immobilization Matrix

Many immobilisation matrices are being used and investigated. Commonly used and cited matrices are discussed in subsequent paragraphs.

Cementitious Materials

Cementitious materials encapsulate radioactive waste in a strong, alkaline, low-permeability, amorphous to crystalline form with long-term durability. Cementitious materials can be used for wide range of LLW and ILW. Cementation is carried out in a drum mixing system or in situ. Advantages of cementation process include low cost, higher throughput, operational simplicity, and product of acceptable quality.

Cementitious materials comprise of cement mixed with granular material to achieve a pourable consistency and include (1) cement grouts, (2) mortar, and (3) concrete. Cement grouts are mixture of ordinary portland cement (OPC) and water, with or without very fine aggregate. The mixture is proportioned to generate a pourable fluid. Mortar is a mixture of cement, water, fine aggregate and additives which are less fluid than grouts. Concrete is formed by mixing of cement, water, coarse and fine aggregate. In order to achieve the desired grout properties ingredients blending agents are used with cementitious immobilization matrices. Some of the commonly used blending agents are pulverised fly ash (PFA), blast furnace slag (BFS) and super-plasticizers.

Bitumen

Bitumen is generally used for immobilizing liquid and wet LLW and ILW encapsulates waste in a viscous, self-sealing, neutral, low-permeable, amorphous solid form with good long-term durability.

Organic Polymers

Organic polymers are suited to beta and gamma emitting LLW as well as ILW. They are used for encapsulation of low permeable, hard, amorphous to semi-crystalline solid waste.

High-Temperature Incineration and Melting

This method is used for LLW and some ILW. High-temperature incineration and melting embed radio nuclides in an impermeable, hard, amorphous glassy solid. The waste embedded with this method will have leaching characteristics better than or similar to borosilicate glass.

Phosphate Ceramics

Phosphate ceramics are used for LLW and ILW with volatile radionuclide. The matrices incorporate radio nuclides in a neutral to alkaline, high-strength, low-permeability, crystalline solid form.

Inorganic Polymers/Synthetic Zeolites

These matrices are usually used for LLW. They encapsulate waste in a low-density, low-permeability, very strong, amorphous, neutral, solid form with leaching characteristics better than or similar to cementitious materials. ILW like radioactive concentrates as well as spent ion exchange resin is solidified using matrix such as polyester styrene.

Radioactive spent resins are transferred to a resin storage tank and excess water is removed using vacuum de-watering system. A required quantity of polymer is premixed with the requisite amount of accelerator and catalyst. The usual accelerator is dimethyl aniline and catalyst is benzoyl peroxide. The polymer is then poured into a product drum.

Glass

This matrix is usually used for HLW but can also be used for LILW. Glass is used for encapsulation of waste in a very strong, impermeable, amorphous, high-density, and acidic to neutral solid form with long-term durability. The process of integrating materials into a glass-like form or glass is called vitrification. Vitrification is frequently used for *solidification* of liquid HLW from the *reprocessing* of *spent fuel*. Glasses have potentially high durability, high chemical resistance. Vitrification generates small volume of waste-form and can be used for incorporating large number of elements.

The most durable materials need very high processing temperatures of more than 1,500 °C at which waste radionuclides occur in volatile form generating large quantity of secondary wastes and diminish the immobilization efficiency. Sulphate in the waste resulting from ferrous sulphamate used for conversion of Pu^{+4} to Pu^{+3} is one of the bothersome components with respect to vitrification. Sulphate as sodium sulphate can be allowed in borosilicate matrix up to 1 wt % maximum. At higher sulphate concentrations, alkali sulphate is formed which is not desirable as this phase has high solubility in water. Presence of this soluble phase harmfully affects homogeneous distribution of radionuclides leading to problems during pouring of vitreous material into storage canisters. Hence, in order to avoid such complications borosilicate glass matrix is used to accommodate sulphate uniformly in the glass matrix (BARC 2011). Hence borosilicates and phosphates, which use lower processing temperatures of around 1,000 °C are used in vitrification of nuclear waste. Vitrification can destroy hazardous organics in the waste and chemically incorporates the waste inorganic matter into a stable glass.

Vitrification involves melting of waste with glass-forming material in order to incorporate the contaminants into macro- and micro-structure of vitrified solid. Waste constituents are immobilised by direct integration into glass structure or by encapsulation.

In the single-stage vitrification process glass forming materials are mixed with wastes to form of a paste. This paste is then fed into the melter. In the two-stage vitrification process the following stages are followed: (1) introduction of the waste concentrate into the calciner where oxysalts decompose into oxides, (2) feeding calcinated waste into melter with additives.

Sugar is usually added in calcinations or melting to restrain Ruthenium volatilisation. Addition of phosphate to the waste feed generates a metal phosphate which acts as a secondary containment and the product is called super-calcine.

Glass Ceramics

These matrices are usually used for HLW. They encapsulate and partly incorporate waste in an impermeable, very strong, high-density, amorphous-crystalline, and acidic to neutral solid form with leaching characteristics superior to borosilicate glass.

Synroc

Synroc, is portmanteau of "synthetic rock". These matrices are usually used for HLW. This matrix incorporates radio nuclides in a very strong, impermeable, very high-density, crystalline, and acidic to neutral solid form with leaching characteristics and durability superior to borosilicate glass.

Natural Crystalline Phases

A natural crystalline phase like Zircon embeds radio nuclides in mono-mineralic solids with good leaching characteristics and durabilities (Bennett et al. 2001).

10.6 Storage

Repositories of radioactive waste storage/disposal facility will have multi-barrier system to separate the waste from the biosphere.

Multi-barrier system includes the natural geological barrier of the host rock as well as an engineered barrier system (EBS). Figure 10.7 shows schematic diagram of basic barriers in a nuclear waste repository. Figure 10.8 shows schematic diagram of an EBS. The EBS comprises of numerous components like waste matrix, container, backfill, repository walls and wall linings.

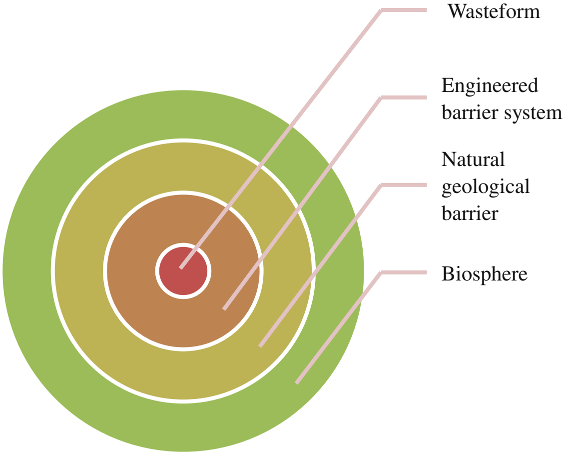


Fig. 10.7 Schematic diagram of basic barriers in a nuclear waste repository

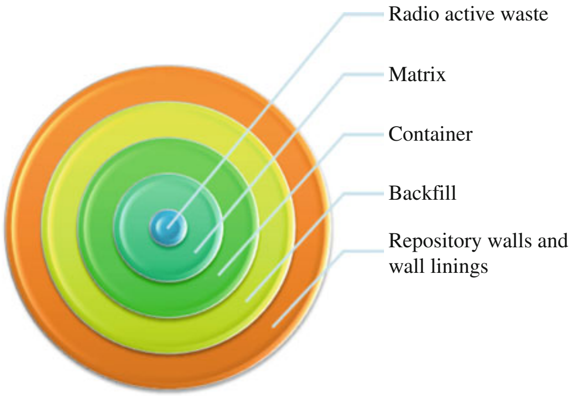


Fig. 10.8 Schematic diagram of an EBS

The various barriers are provided initially to hold the radionuclides and then to restrict radiation release to the environment. Geological repositories are provided mainly for: (a) isolating waste from human activities, (b) protecting the environment, (c) limiting release from the degrading EBS, and (d) diluting and dispersing the flux of long lived radionuclides.

10.7 Disposal

Disposal comprises of emplacement of radioactive waste with assurance for safety in a disposal facility without the intention of retrieval. Figure 10.9 shows disposal options for various classes of radioactive wastes. The safety is achieved by placing natural/engineered barriers around the waste in order to limit the release of

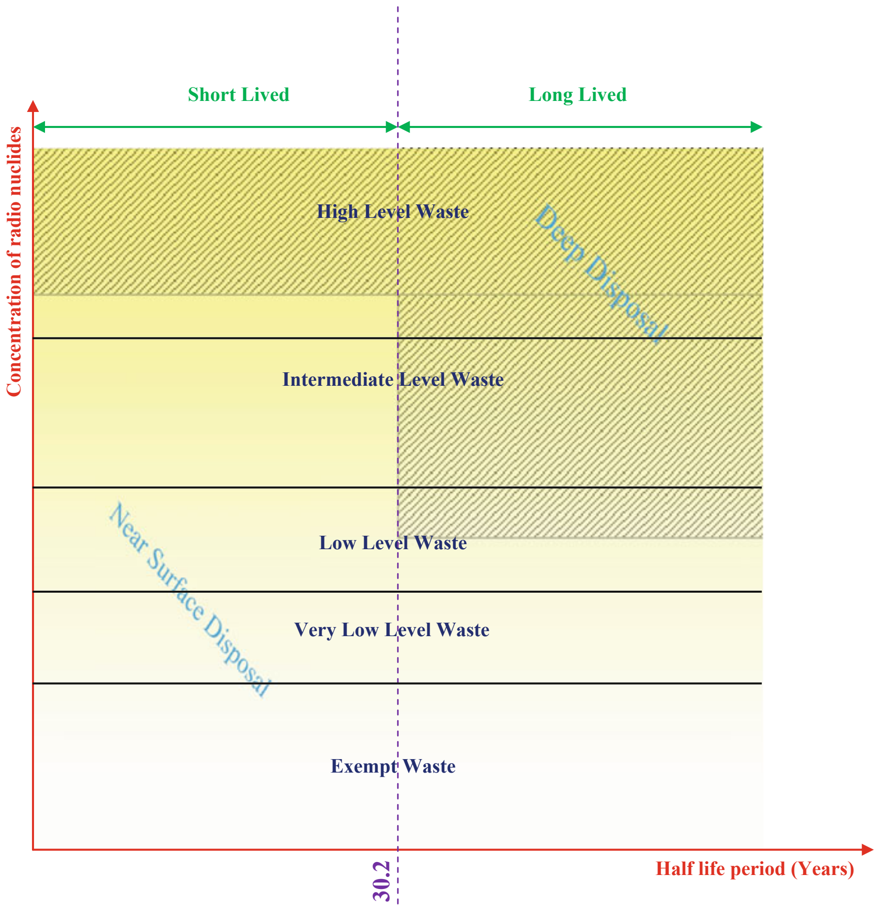


Fig. 10.9 Disposal options for various classes of radioactive wastes

radiation into the environment. A system of multiple barriers is usually adopted to ensure isolation and minimization of release of radionuclides into the environment. Barriers can be metal wall of a container, or backfill or host rock with high sorption (adsorption and absorption) capability. The radionuclides in the contained waste will undergo decay thus reducing hazard with time. Even though radioactive waste is disposed for concentrate and contain, disposal may also include the discharge of waste into the environment in liquid and gaseous form within authorized limits, with adequate dispersion.

HLW management and disposal are amongst the most difficult problems in nuclear power industry. As per Amaral et al. (2007) about 190,000 metric tonnes of HLW was in temporary storage awaiting disposal.

The different categories and methods adopted for disposal are listed in Table 10.2.

Table 10.2 Disposal options for various radioactive waste categories

Surface dose/activity	Disposal options
<2 mGy/h	Stone lined earth trenches
2–20 mGy/h	RC trenches
20–500 mGy/h	RC trenches
>500 mGy/h	Tile holes
Waste bearing alpha activity (< 4000 Bq/g)	RC trench and tile holes
Waste bearing alpha activity (>4000 Bq/g)	Tile holes

In order to control/minimise discharge through air route installations shall have efficient off-gas cleaning system like venturi scrubber, packed bed scrubber, cyclone separators, and high-efficiency air filters to retain particulate radionuclides.

Low-level waste streams need treatment to reduce their concentration to statutory limits by filtration, ion-exchange, chemical treatment, solar evaporation, steam evaporation, and membrane processes (IAEA 1983).

As per the Chinese policy spent nuclear fuel (SNF) shall be reprocessed followed by vitrification and final disposal. As per the long-term research and development (R&D) plan published by China for geological disposal of HLW in 2006, following steps have been adopted: (1) laboratory studies as well as site selection for HLW repository (2006–2020), (2) in situ underground tests (2021–2040), and (3) repository construction (2041–2050) and operation. The site characterization has been performed at the Beishan site in Gansu Province (Ju 2010).

SNF accumulated from light water reactors in China is estimated to be around will be 1,000 t by 2010, furthermore 2,000 tonne by 2015. Further about 1,000 tonne of SNF will be accumulated every year after 2020. The since 1986 china did Nationwide screening (1985–1986) followed by regional (1986–1989) and areal screening (since 1990) for finalizing disposal site.

Radioactive waste disposal involves placing radioactive waste in a dedicated facility meant for disposal.

Near-surface disposal is suitable option for disposing of short-lived LILW. Near-surface disposal include facilities wherein waste is emplaced on the surface or at a depth of few meters. Retention period of short-lived LILW varies from tens to hundreds of years.

Geological disposal/storage is used for HLW, spent nuclear fuel (SNF), spent sealed radioactive sources (SRS) and long-lived LILW. Geological disposal can be wet, dry and very deep. In the wet deposit engineered repository located at a depth of around 500 m where water ingress and saturation is unavoidable. In very deep disposal waste is emplaced at depths of 3 km or more.

10.7.1 Near Surface Disposal Facilities

The various disposal modules adopted in NSDFs are: (1) reinforced concrete trenches (RCT), (2) stone-lined earth trenches (SLT), and (3) tile holes (TH). These modules are usually below the ground. But depending on the local geo-hydrological conditions, facilities could be partly/completely above ground as well. The disposal sites are closed by wall to restrict unauthorized access. Bore-holes of 4–7 m deep are employed at appropriate locations for monitoring groundwater periodically apart from analysis of soil and vegetation for uptake of radioactivity. Inspection pipes are provided in RC trenches to monitor after closure of the trench. Further radiation survey of the complete site is done at predetermined intervals.

Performance assessment of NSDFs is done through field investigations and mathematical models. Safety assessments are carried out for NSDFs using mathematical models considering the nature of the facility and geochemical behaviour at the site.

10.7.2 Stone-Lined Earth Trenches

These are used for potentially active wastes. Stone-lined earth trenches are shallow excavations 1–4 m deep provided with stone lining. These trenches are backfilled and closed with a soil cover of about 1 m thick after disposal. Vermiculite, bentonite and other soil with good sorption properties are suitable for backfilling materials.

10.7.3 Reinforced Concrete Trenches

These trenches are typically 2.5 m wide, 4.8 m deep and 15 m Long with outer containment wall thickness varying from 750 mm at the bottom to 350 mm at the top (Raj et al. 2006) are closed with pre-cast concrete slabs with water proofing (Fig. 10.10).

10.7.4 Tile Holes

Conditioned waste packages are stored in tile holes which are circular and about 4 m below ground made of steel shell and concrete lining (Bansal et al. 1991). The concrete tile hole is formed by digging a hole, and placing precast pipe sections on

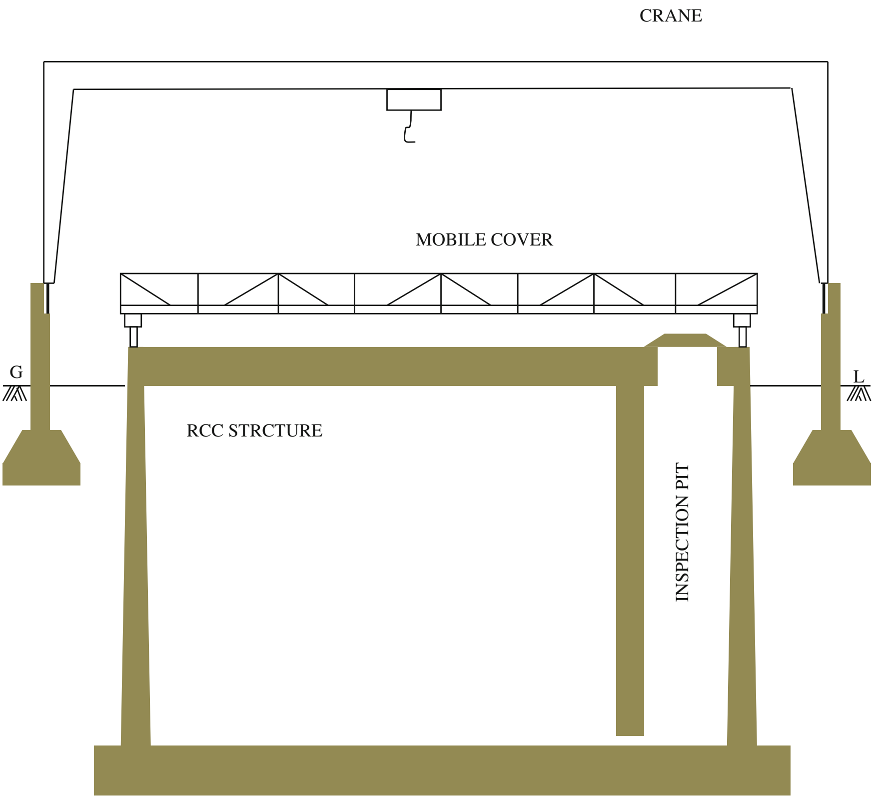


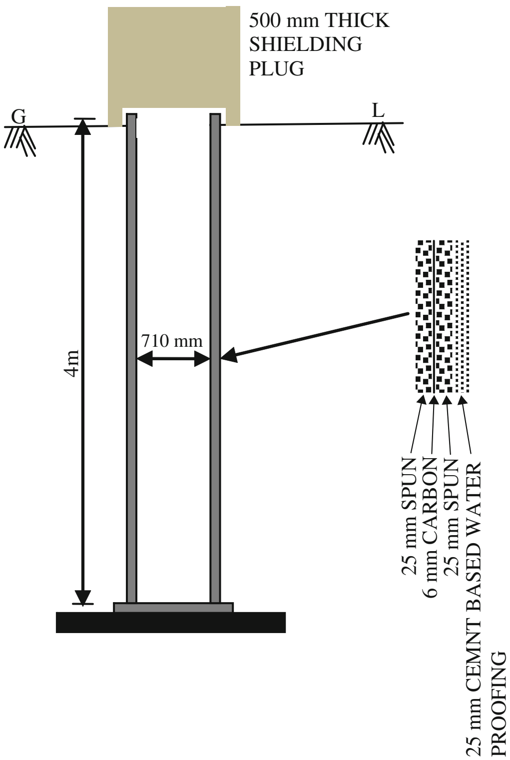
Fig. 10.10 Concrete trench for disposal of radioactive waste

a concrete base. After these precast pipe sections are attached, the hole is back-filled and paved over (Fig. 10.11).

10.7.5 Geological Disposal

Disposal of HLW in deep geological is done for vitrified wastes at nearly 500–5,000 m depth in appropriate host rocks like granite, gneisses, charnockite, basalt, etc. In deep borehole disposal of SNF and HLW are emplaced in boreholes at depths of about 2–5 km below the land surface. Geographically-distributed deep borehole disposal sites can decrease risk due to setting up of centralized storage and disposal. Each borehole could hold about 100–200 metric tonnes (MT) of radioactive waste. Deep bore well disposal facility shall be located at suitable geologic strata. Isolation capability and reliability depends on geologic settings (Fig. 10.12).

Fig. 10.11 Schematic diagram of tile hole



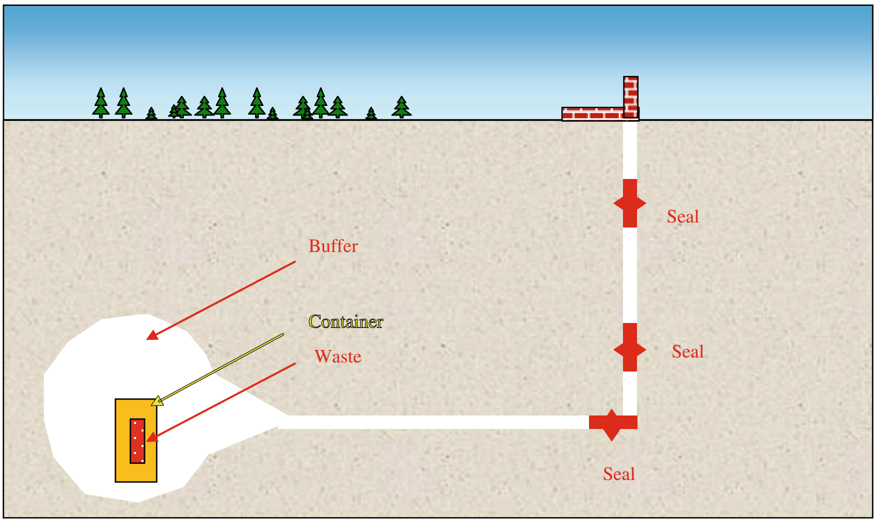


Fig. 10.12 A conceptual drawing of geological disposal

Concept of multiple barriers is the basis of geological disposal. The barriers include both 'engineered' and 'natural'. The engineered barrier components are: solid waste, its container, and a backfill or buffer material placed between the rock/soil and the container. In salt formations, where groundwater is absent, crushed salt is used instead of buffer. Rocks and soils between the Earth's surface and repository act as natural barrier. The container protects the radioactive waste as well as prevents water reaching it for several hundred years by which time, most of the radio activity would decay to safe level. The buffer or backfill protects the container from water and mechanical disturbance due to earthquakes.

10.8 Surveillance and Monitoring

Geological disposal system are monitored with the following generally accepted principles: (1) follow both conventional and radiological safety, (2) long term safety should not depend on post-closure monitoring, (3) design of a disposal system shall be assure long term safety, (3) monitoring activities should not affect safety of a disposal system, (4) monitoring shall continue in future generation if required.

Monitoring activity should start prior to commencement of any activity at site and should be carried throughout the life cycle of the disposal activity.

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Chapter 11
Health and Safety Issues

World is not a safe place to live. All human activities carry some risk of injury. To be safe, people should think about their job and plan well for possible hazards. To avoid injury or death, people must understand and recognize hazards. The simplest way for safe living is: (1) recognize hazards, (2) evaluate hazards, and (3) control hazards.

Waste management is becoming a more and more complex matter. Effects on the health of human exposure are causes of concern. All the activities while managing solid waste involve risk with respect to safety. Injury and death can occur to waste producer, collector, transporter, recyclers and reusers. The risks occur from the point of waste generation to the ultimate disposal. The UK waste industry usually reports approximately 4,100–4,300 accidents per year, while the private companies normally report approximately 1,700–2,000 accidents per year (HSE 2004).

In an industry safety is important because: (1) safety would affect the wages of the people who are ill or injured, (2) loss of productivity caused by disruption to business, (3) damage to products, equipments, (4) costs of investigation and correcting a problem, and (5) fines and legal costs if prosecuted. But solid waste in many countries is an unorganised sector with people disposing and handling waste the way they like it.

Handling and storing waste involve various operations like hoisting with a crane, carrying bags or materials, driving a truck loaded with waste, and stacking waste in drums and barrels. The efficient storing and handling of materials are vital to waste management. Inappropriate storing and handling of materials result in costly injuries.

In addition to the training and awareness which apply to general safety principles like proper work practices, equipments, and controls can help bring down the number of accidents during waste management. Whether moving waste manually or mechanically, the concerned persons should understand the hazards associated with the work at hand and know how to minimize the risk associated.

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Many injuries can result due to improper storing and handling of materials. Waste-handlers should have the knowledge of the methods for eliminating and minimizing the occurrence of accidents.

Bending, twisting, turning, falling objects, tumbling of improperly stacked materials, are the more common movements that cause injuries. Waste-handlers should be aware of injuries that can occur when handling materials, including the following:

- Strains and sprains from handling waste improperly or from carrying waste that are too large/heavy,
- Bruises and fractures caused while handling waste, and
- Cuts and bruises caused by falling of improperly stored objects.

Health risks from waste depends on (1) the composition of waste (e.g., toxic, temperature, sharps, infectious substances and other chemical/physical properties), (2) the products and by products of waste decomposition/reaction, (3) work condition (e.g., traffic, waste handling machineries), (4) energy usage (e.g., fuel, electricity), (5) health of individuals, (6) disaster in the area, (7) the methodology/technology adopted for handling/processing of waste, (8) the climatologically/environmental setup of the location, (9) personal protective equipment, and (10) personal hygiene practice, (11) extent of waste regulation, (12) efficiency of regulators, and (13) efficiency of waste handling.

The risk associated with a waste depends upon the waste and the recipient. As expected, the wastes that are infectious/hazardous are more dangerous compared to the wastes without infections/hazardous substances. Similarly, wastes with sharps, debri, allergic substances will impose more health hazards. In the developed countries, hazardous/infectious wastes are regulated and segregated at source to be managed afterwards. In the developing countries, a considerable portion of the faecal matter would enter solid waste stream due to inadequate sanitation and sewerage system. Children/old people are particularly vulnerable to toxins and infection as they will have less resistance to deceases.

Many waste generation/collection point is charecterisised by the following: (1) changing weather, (2) undefined workspace and exit, (3) absence of fire precautions, (4) absence of lavatories and showers, (5) absence of potable water supply, (6) absence of clean eating area, (7) absence of controlled lighting, (8) absence of safe access, (9) absence of first aid, (10) absence for oxygen supply, (11) uncontrolled work environment temperature. With only the exception in sophisticated waste handling facilities waste handlers would work discreetly like rag-picker shown in Fig. 11.1.

Health can be affected due to injury or infection as detailed below: (1) injuries due to handling waste, (2) respiratory sickness due to air pollutants, (3) infections due to direct contact with infectious material (Fig. 11.2), (4) injuries due to surface subsidence, fires, and slides, (5) sickness due to anoxic conditions, (6) sickness due to water pollution, (7) attack by stray animals residing in waste dumps, (8) sickness due to increase in vector population, (9) noise, (8) fires, and (9) toxicity. In

Fig. 11.1 Rag-picker picking waste without safety concerns

Fig. 11.2 Tubings contaminated with body fluid

exceptional cases radioactive waste can enter municipal solid waste making it more hazardous to the people coming in contact with them.

Waste pickers are often subject to injury and sickness. Children are more susceptible to toxins as they consume more water, air and food per unit of body weight. Metabolic activities of the children are underdeveloped to excrete and detoxify toxins, and any disturbance during their growth can easily disturb growth of their organs (Landrigan et al. 1998).

HHW in the domestic waste is not devoid from safety issues as they contain: (1) pressurized gas containers, (2) aerosols, (3) WEEE, (4) oils, (5) asbestos, (6) paints and adhesives, (7) flammable liquids (e.g. thinners and solvents), (8) agro-chemicals (pesticides etc.), and (9) household Chemicals.

Wastes in the developing countries are thrown openly making it unsafe as compared to collection of waste in sealed plastic bags and covered dustbins in developed countries. Due to strong regulatory framework, waste handling is mechanized in developed countries making them safer for waste-handlers. Due to the accumulation of waste near homes general public in the developing countries have more unsafe waste compared to their counterparts in the developed world.

Statistics are not maintained and published in developing countries making it difficult to make comparison of health and safety issues with that of developed countries. The major injury accident rate in the UK for the waste industry in the year 2001/2002 was around 330 per 100,000 workers which are more than national rate of 101 per 100,000 workers. The fatal injury accident rate in waste sector during same period was estimated to be around 10 per 100,000 workers which (HSE 2004).

The developing countries have greater safety issues for the following reasons: (1) manual collection without personal protective equipments, (2) rag pickers are cashless, homeless and live with no or little community help/support, (3) doctors and health care workers may not serve the waste handlers properly, (4) lack of specific safety regulations for waste handling in unorganised sector, and (5) absence of safety training/awareness.

There are several episodes which imply the importance of safety in waste disposal. Illegal dumping of used needles and syringes on 15 September 1999, in the Western Cape Town, South Africa resulted in the use of syringes by children for playing. 54 children, who were involved in this incident, were eventually found to be free from infection after an extended period of anxiety and noteworthy clinical intervention (de Waal et al. 2006).

Apart from direct injury indiscriminate disposal of solid waste would also encourage breeding of street animals. Consider the example of Bangalore, India. The city had 0.143 million stray dogs according to 2007 dog census. The city also suffered 12,796 dog bites during April 2008–March 2009 out of which 45 % is attributed to pets (Chitra 2011). The attack of street dogs has been course of several deaths every year. It is also a common scene in Bangalore in recent years that some dogs kill and drag sleeping children of poor and/or homeless. The increase in stray dogs in the dump sites of habitats adjacent to forest areas will also attract predators of dogs like cheetah and foxes.

11.1 Required Precautions During Manual Operation

Wastes in the developing countries are often dumped in open spaces or footpaths (Fig. 11.3) and workers have to manually collect waste with shovels or by hand (Fig. 11.4). Such handling should be done with precaution and after wearing proper personal protective equipments.

When moving bulky waste materials or bales of compacted/shredded manually, waste handlers should attach holders/handles to loads. Waste handlers should seek help during the following situations while handling objects: (1) when an object is too bulky to handle individually, (2) when waste handler cannot see over or around a load, or (3) when waste-handler cannot handle a load safely.

Fig. 11.3 Waste handling without safety precaution

Fig. 11.4 Poverty and urge to earn more often compel one to avoid safety precautions

Apart from physical injury humans or animals can be injured due to toxicity. Toxicity is the capability of a chemical or combination of chemicals in a waste to injure upon contact. Toxicity can be acute or chronic. In case acute toxicity effect/ mortality will occur within hours/days no more than two weeks after a single or multiple brief acute exposures. In case of chronic toxicity, adverse effects occur after a lengthy period of exposure of small quantities of the toxicant.

Ingestion brings toxic substance into contact with the gastrointestinal (GI) tract tissues. The GI tract will absorb toxic chemicals if ingested with food and water. The absorption degree depends on the hydrophilic or lipophilic nature of the ingested toxic substances. Lipophilic compounds are well absorbed as the chemical will easily diffuse through the membranes of the cells. Hydrophilic compounds cannot cross the cell and will be carried across by transport systems in the cells.

Absorption of toxins occurs easily in some region of the body compared to other regions. Absorption of toxicants into the bloodstream through skin is slowed down by the densely packed strata of rough, keratinized epidermal cells. Toxic chemicals can be categorized into irritants, central nervous system (CNS) depressants, asphyxiants and systemic toxicants based on physiological effect on the exposed species. Inhalation brings toxic substances into contact with the lungs. Gases cross the cell of the lungs by simple diffusion. Hence, the absorption in the lung is high as the surface area is high and blood vessels are adjacent to the exposed surface area. Rate of absorption depends on the solubility of the chemical in blood.

Irritants are chemicals that cause pain, erythema as well as swelling of the respiratory tract, skin, eyes, or GI tract. Asphyxiants deny oxygen to cells of the organism thereby slowing/halting metabolism. CNS depressants are chemicals that cause deadening of the nervous system. Systemic toxicants are chemicals that exhibit their effect upon a specific organ and possibly away from the site of entry.

Waste-handler should use the following personal protective equipment for safe operation: (1) hand and forearm protection, like gloves, for waste with rough or sharp edges, (2) eye protection, and (3) steel-toed safety boots or shoes.

Waste-handlers should use blocking materials to handle loads safely. Blocking materials should be (1) strong and large enough to support the object safely, (2) devoid of cracks and rots, (3) devoid of rounded corners and splintered pieces.

As per HSE (2004) the accidents predominantly occur in the UK during solid waste collection with noteworthy numbers also occurring while loading/unloading as well as on-site transfer activities.

Manual handling of industrial waste involves shoveling by hand into storage containers followed by manual loading into trucks. The manual salvaging is done by hand, picking out useful items. Handling waste without protective clothing is likely to cause injury and other deceases when waste is mixed with chemicals. Cuts are caused by broken glass or sharp metals and chemicals may cause skin burns. Other health risk includes respiratory problems from dust inhalation, and carcinogenicity from toxic chemicals present in waste. People handling waste from tanneries or hide processors will be exposed to diseases such as anthrax.

11.2 Required Precautions for Moving Materials Mechanically

According to HSE (2004), accidents occur while being struck by waste collection vehicles, accidents during trips, being struck by falling objects are significant. Organized waste processing plants provide necessary personal safety equipment, training to employs in addition to proper training (Fig. 11.5).

Use of mechanical equipment to store and move materials increases the chances of waste-handler injuries. Waste-handler must be aware of manual handling safety concerns as well as safe equipment operating techniques. Waste-handler should evade overloading equipment while moving waste mechanically. The size, weight and shape of the object being moved should be considered while choosing the type of handling equipment. All material handling equipments have rated capacities that identify the maximum weight the equipment than can handle safely and the conditions under which it can handle the weight. Waste-handlers must make sure that the capacity of equipment is displayed on the equipment and does not exceed except while testing. Waste-handlers shall have knowledge of powered equipment, storing and stacking of material.

When collecting waste with a powered truck, waste-handler should do the following: (1) load should be placed at the centre on the forks as close to the mast to avoid load falling or truck tipping, (2) avoid overloading lift truck to avoid tipping over, (3) avoid extra load on the rear of a counterbalanced forklift, (4) adjust the object to the lowest position when moving, (5) follow the operational requirements of truck manufacturer, and (6) cross-tier and pile all stacked loads properly.

To reduce the magnitude of an injury while working near/with cranes, waste-handlers should take the following precautions: (1) post load rating charts in a place clearly visible to crane operator, (2) keep hoisting ropes and chains free of twists or kinks, and (3) ensure timely inspection and maintenance.

11.3 Safety During Storage and Transport

Storage and transportation are two important solid waste management components. Storage could happen on site as well as off site. Irrespective of where the material is stored precaution should be taken to handlers as well as general public. Storage on road side in developing countries often hinders traffic (Fig. 11.6).

Stored waste must not create a hazard for waste-handlers. To prevent hazards while storing materials, waste-handler must:

- Keep storage areas free from accumulated waste to avoid fires, tripping, explosions, rodents and vectors,
- Place waste at least 2 m from hoist ways and at least 3 m away from walls,

Fig. 11.5 Organised waste processing plants provide necessary personal safety equipment, training to employs in addition to proper training

Fig. 11.6 Waste stored on a road side

- Equip waste-handler who works at high level with safety belts,
- Separate non-compatible material,
- Place secure waste by stacking, interlocking or blocking, to prevent it from falling, sliding, or collapsing.

The waste handling in slippery places like abattoir is shown in Fig. 11.7 will not only pose injuries but also expose to pathogens. Over burdening of vehicles as shown in Fig. 11.8 will not only risk the waste handling personnel but also general public.

Corrosive, oxidizing, and reactive chemicals in waste create similar hazards and hence, require precautions as that of handling flammable materials. Inadvertent intermixing may cause serious adverse reactions which can lead to the release of flammable/toxic materials and gases resulting in fires and explosions. The following measures should be observed when handling such chemicals:

Fig. 11.7 Slippery floor in a slaughter house

Fig. 11.8 Waste overloaded on a truck

- Corrosive, oxidizing and reactive chemicals must be separated from flammable and chemicals of incompatible class (acids vs. bases, water sensitive vs. water based, oxidizers vs. reducers, etc.) to minimize intermixing during spills,
- Workers who are needed to handle corrosive, oxidizing, or reactive waste should be provided with specialized training,
- People handling corrosive, oxidizing, or reactive waste should wear, appropriate personal protective equipments (PPEs) like gloves, splash suits, aprons, face shields or goggles, etc.
- Where corrosive, oxidizing, or reactive waste are handled or stored, qualified first-aid should be ensured at all times.

The handling of asbestos containing materials (ACM) should only be performed by specially trained personnel.

Figure 11.9 shows a good example wherein waste storage and proper work place discipline can reduce injury and accidents. Figure 11.10 is a bad example depicting what should not be done.

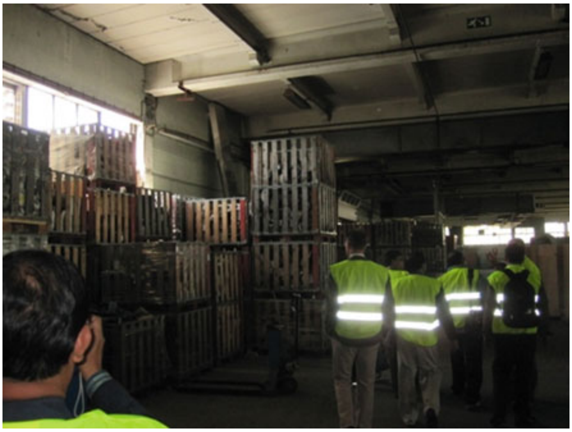

Fig. 11.9 Waste storage and proper work place discipline can reduce injury and accidents

Fig. 11.10 Waste being loaded on truck without safety concern

Many chemicals react violently when mixed accidentally/intentionally. These chemicals are called as *incompatibles*. Mixing or storing the following chemical classes together would result in dangerous reaction: (1) acids and alkalies, (2) bleaches, (3) oxidizing agents, (4) reducing agents, and (5) solvents and flammables.

Some major incompatible chemicals that often lead to hazards are: (1) ammonia with hypochlorite bleach, (2) nitric acid with acetic acid, (3) nitric acid with sulphuric acid, (4) 1-butanol with strong mineral acids, (5) n-butyl amine with copper and copper alloys, (6) n–n-dimethyl formamide with halogenated hydrocarbons, (7) ethyl acetate with strong alkalies, (8) ethylene dichloride with oxidizing materials, (9) ethylene glycol with sulphuric acid, (10) MEK peroxide (hardener for polyester casting resin) with anything flammable, (11) 1,1,1 trichloroethane with caustic soda and caustic potash.

Table 11.1 Non-compatible chemicals

	Non oxidizing mineral acids	Oxidizing mineral acids	Organic acids	Alcohols and glycols	Aldehydes	Amides	Aliphatic and aromatic amines	Azo compounds, diazocompounds and hydrazines	Carbamates	Caustics	Cyanides	Dithiocarbamates	Esters	Ethers	Inorganic flourides	Aromatic hydrocarbons	Halogented organics	Isocyanates	Ketones	Organic sulphides and mercaptans	Alkali and alkaline earth	Elemental metal and alloys in powder, vapour and sponge form	Metals and other alloys in pieces	Toxic metal and metal compounds	Nitrides	Nitrites	Organic nitro compounds	Aliphatic and unsaturated hydrocarbons	Aliphatic and saturated hydrocarbons	Organic peroxides and hydroperoxides	Phenols and cresols	Organophospates, phospothioates, phospodithioates	Inorganic sulfides	Explosives	Combustible and flamable material	Epoxides	Polymerisable compounds	Strong oxidising agents	Strong reducing agents	Water and mixture containing water	Water reactive substance
Organic acids		G																																							
Alcohols and glycols		F	P																																						
Aldehydes	P	F	P																																						
Amides		G																																							
Aliphatic aromatic amines		G																																							
Azo compounds, diazo compounds and hydrazines	G	G	G	G																																					
Carbamates	G	G						G																																	
Caustics									G																																
Cyanides	G, G	G,G	G,G					G																																	
Dithiocarbamates	G, F	G,F	G,G		G, G		U	G																																	
Esters		F						G																																	
Ethers		F																																							
Inorganic flourides	G	G	G																																						
Aromatic hydrocarbons		F																																							
Halogented organics	G	F,G					G	G		G																															
Isocyanates	G	F,G	G	P			P	G		P,G	G	U																													
Ketones		F	G																																						
Organic sulphides and mercaptans	G, G	F,G						G																																	
Alkali and alkaline earth	G, F	G,F	G,F	G,F	G, F	G	G	G	G	G	G	G,G	G				E	G	G	G																					
Elemental metal and alloys in powder, vapour and sponge form	F, G	F,G	G					E,F, G	U	G,H							E	G		G,F																					
Metals and other alloys in pieces	F, G	F,G						F,G									F																								
Toxic metal and metal compounds																																									
Nitrides	F, G	F,E	G	G,E	G			U	G	U	G	G	G				G	U	G	G	E																				
Nitrites	G, G	F,G								U											P			S	G,E																
Organic nitro compounds		F,G								E											G,E				G,E																
Aliphatic and unsaturated hydrocarbons		F																				E																			
Aliphatic and saturated hydrocarbons		F																																							
Organic peroxides and hydroperoxides	G	E		F	G		G	E,F	F, G		E, G	F,G					E		E	F,G	E	P,G		G	G,E	P,G		P													
Phenols and cresols		F						G										P			G				G																
Organophospates, phospothioates, phospodithioates	G	G						U		E																				U											
Inorganic sulfides	G, G	F,G						E																						G											
Epoxides	P	P	P	P	U			P	P	P	P	U								P	P	P		P	P					P	P	U	P								
Combustible and flammable material	G	F,G																			G,F				G,F					F, G											
Explosives	E	E	E					E		E			E								E	E	E	E	E					E	E		E	E	E						
Polymerisable compounds	P	P	P					P		P	P	U									P	P	P	P	P					P	P		P			E					
Strong oxidising agents	G		G	F	F	F, G	F, G	E	F, G		E, G	F,G	F	F		F	G	F, G	F	F,G	F,E	F,E	F		F,E	F,G	E	F	F	G	F	F,G	F,G	F,G	F , G	E	F, G				
Strong reducing agents	G	F,G	G	G,F	G, F	G	G	G				G	F				E	G	G							G	E			E	G	G,G			G	E	P, G	F, E			
Water and mixture containing water						G												G			G	G			GF								G,G						G, G		
Water reactive substance																																									

F : Fire
E : Explosion
P : Violent Polymerization
G : Toxic Gas Generation
G : Innocus Nontoxic Gas Generation
F : Flammable Gas Generation
U : May be Hazardous

Extremely Reactive
Heat Generation
Solubalization of Toxic Substance

Table 11.2 Example of reaction leading to toxic gas formation

Sl.No.	Reactant A	Reactant B	Product
1.	Arsenical materials	Reducing agent	Arsine
2.	Azides	Acids	Hydrogen azide
3.	Cyanides	Acids	Hydrogen cyanide
4.	Hypochlorites	Acids	Chlorine or hypochlorous acid
5.	Nitrates	Sulphuric acid	Nitrogen dioxide
6.	Nitric acid	Copper/brass/heavy metals	Nitrogen dioxide
7.	Nitrites	Acids	Nitrous fumes
8.	Phosphorus	Caustic alkalis/reducing agents	Phosphine
9.	Selenides	Reducing agents	Hydrogen selenide
10.	Sulphides	Acids	Hydrogen sulphide
11.	Tellurides	Reducing agents	Hydrogen telluride

Table 11.1 shows a group of chemicals, which react with each other creating hazardous situation. Table 11.2 gives some of the specific examples which results in toxic gas formation. But it is often not possible to protect general public and environment from these chemicals which is thrown haphazardly without precaution.

11.3.1 Stacking Materials

Stacking materials will be dangerous when waste-handlers do not take precautions. Falling objects and collapsing waste can pin or crush workers, causing injuries or death. To avoid injuries when stacking objects, waste-handler should do the following:

- Stack waste only up to more than 4 m high if it is handled manually, and up to more than 6 m if using a forklift,
- Remove all sharp objects stacking,
- Stack and level waste on properly supported bracing,
- Make sure that stacks are self-supporting and stable, and
- Store baled waste more than 0.5 m from walls or partitions inside a building,
- Bundles and stack bags in interlocking rows,
- Band boxed waste or secure them with cross-ties,
- Block the bottom tiers of barrels, drums, and kegs to avoid rolling when stored on their sides,
- Stack drums, kegs and barrels symmetrically,
- Place sheets of plywood, planks, or pallets between every tier of barrels, drums, and kegs,
- Stack and block cylindrical materials to prevent tilting or spreading unless they are in racks (Fig. 11.11),
- Chock the bottom tier of barrels, drums, and kegs on each,

Fig. 11.11 Stacking of cylindrical materials

Fig. 11.12 Sprinkler system in hazardous waste TSDF

- Colour the walls or posts with stripes to indicate stacking heights for quick reference, and
- Observe height limitations while stacking materials.

Accidents in waste yards are not only injurious to waste handling people but also to general public. Fire accident in hazardous waste storage facility can lead to reaction that could generate hazardous fumes killing thousands of people in the vicinity. Figures. 11.12 and 11.13 show a sprinkler system and emergency shower along with eyewash in hazardous waste Treatment Storage Disposal Facility (TSDF). Such systems are often ensured by regulatory authority prior to commissioning of waste handling/storage facility. But plant operators should have higher standards for safety within the establishments to safeguard employees.

Fig. 11.13 Emergency shower and eyewash in hazardous waste TSDF

11.3.2 Safety During Transportation

Accidents during transportation are one of the major causes of injuries as well as deaths in the world and waste transportations not an exception. Statistics of injuries/fatalities during waste transportation is often combined with other.

Waste transportation safety initiatives should include: (1) emphasizing importance of among drivers, (2) adopting limits for trip duration, (3) improving driving skills, (4) arranging driver rosters to avoid overtiredness, (4) avoiding dangerous times and routes of day, (5) use of speed control devices, (6) remote monitoring of driver actions, (7) avoid alcohol consumption during driving, (8) avoiding overburdening, (9) proper labelling, (10) avoid transportation of incompatible chemicals at the same time, (11) equip vehicle with fire extinguishers and train drivers to use them, (12) avoid transporting waste with sparks and fire, (13) emphasize drivers and waste handlers to use proper personal safety equipment, (14) regular

Fig. 11.14 Docks and ports are slippery posing special safety issues

maintenance of vehicles, and (15) use of genuine spare parts to reduce accidents caused by malfunction of equipment or premature failure.

In addition to the above precautions, procedures for hazardous waste transportation should include: (1) labelling of containers which shall include hazards, quantity, and shipper contact information, (2) providing shipping document that describes the associated hazards, (3) ensuring that the volume, nature, integrity and protection of packaging are suitable for the quantity and type of hazardous waste and modes of transport involved, (4) ensuring sufficient transport vehicle specifications, (5) training staff involved in the transportation about proper shipping procedures and emergency procedures, (6) providing the means for emergency response on call, (8) providing integrated marine dangerous goods (IMDG) code for sea transport, and (7) integrated air transport association (IATA) requirements for air transport.

Conveyors are one of the components of waste handling process in mechanised waste processing facilities. While using conveyors, hands of waste handler may get caught in nip points, or struck by falling object off the conveyor, or get caught and drawn into the conveyor. To avoid such a scenario waste-handler should: (1) install an emergency pull cord or button to stop the conveyor, (2) provide emergency stop cables which extends the entire length conveyor belts, (3) avoid riding on a waste-handling conveyor, (4) install proper guards to conveyors, and (5) cover screw conveyors except at discharging and loading points.

Fly-tipping (illegal deposit of waste onto land that does not have a permit to accept such waste) can pose a stern threat to the human health, environment and wildlife. The costs related with cleaning up such illegally dumped waste in the UK is around £100–£150 (Kumbang and Smethurst 2008)

Marine transfer stations are used in small islands and coastal area. Such station are slippery and waste handlers are exposed to hazards involved in wet ports (Fig. 11.14).

11.4 Safety During Treatment and Disposal

Safety and health implication of treatment and disposal of waste is a complex issue. With regards to landfills, an extensive variety of exposure pathways and scenarios are involved, leading to difficulties in estimating the health risks. In respect of incinerators, the major concern with respect of health is inhalation of air pollutants arising from combustion and from incomplete combustion. Contact with contaminated soil and consumption of contaminated food/water are also major concerns.

11.4.1 Safety Issues During Treatment

As discussed earlier some chemicals are not compatible with others and may burst into flames immediately or hours after mixing, emit toxic gases, or bubble and fizz out of the container. Health and safety issues during composting are important as it is a biological process. If prepared properly, compost should eradicate most pathogens. Working with a waste prior to composting is likely to lead to potential exposure to pathogens. It is also noteworthy that the microorganisms will have their presence in the air.

11.4.2 Safety Issues in Dumpsite

Improper disposal of chemicals may cause unforeseen problems. Chemicals disposed improperly will filter down to the water table. It might take years, but they will eventually pollute the water below. Some chemicals washed down the drain produce flammable vapors which can collect in stand pipes and explode.

Untreated oxidizers can react with organic material as oxidizers can react with organic waste and spontaneously combust. For example, automobile brake fluid when mixed with sodium chlorate will burst into flames.

The following groups of chemicals should not be mixed each other: (1) solvents, (2) detergents, (3) acids, (4) alkalies, (5) bleaches, and (6) ethyl ether. Solvents which include paint, varnish, polymer residues, toluene and naphtha should be collected in glass bottles. Waste containing dissolved heavy metals such as copper, zinc, lead, cadmium and mercury are toxic and can kill flora and fauna including microorganisms in soil and water.

Fig. 11.15 Waste disposed at the outskirts of a city

Waste dump sites are much hazardous compared to land fill site due to unrestricted access, absence of fire fighting equipment, no control on quantity and type of waste dumped. Hundreds of people were killed by the collapse of an open dump in July 2000 at the Quezon City garbage dump on the outskirts of Manila. The rag pickers intentionally put fire to separate metal from wires, and other electrical equipments. Municipal authorities and their contractor would dump the waste in the outskirts to save costs of 'disposal' (Figs. 11.15 and 11.16).

11.4.3 Safety Issues in Landfill Site

Landfill fires can occur above ground (surface fires) or underground (subsurface). Surface fires occur on the working face and are usually easily discovered. Subsurface fires start out small and localized and if unattended/undiscovered can spread and become difficult to extinguish. Deep seated fires are cannot be extinguished immediately and hence problematic. Constituents and hazardous nature of landfill the smoke depends on chemicals present in the waste.

Surface fires occur in newly deposited and uncompacted waste. These fires can be fuelled by LFG. Surface fires are usually low temperature burning of waste characterised by the emission of dense white smoke which contains smoke, organic acids, steam, dioxins, furans, polyaromatic hydrocarbons (PAHs), volatilised heavy metals and other volatile compounds. Combustion of the volatiles may not be complete due to burning of tyres or plastics due to insufficient oxygen and temperature resulting in the emission of black smoke. Contaminants released are likely to include carcinogens such as. If plastics containing chlorine, such as PVC, are involved, acidic hydrogen chloride may also be discharged.

Table 11.3 gives some of the examples of major fire accidents in landfills. Landfill fires are common in the summer and spring when there will be higher

Fig. 11.16 Chemicals disposed improperly

Table 11.3 Examples of major landfill fires

Year	Description	Reference
1969	Fire accident in Winston-Salem, North Carolina, USA	(USACE 1984)
1975	Fire accident in Sheridan, Colorado, USA	(USACE 1984)
1983	Destruction of residence due to explosion across the street from a landfill in Cincinnati, Ohio, USA	USEPA (1991)
1984	Destruction of house due to migration of landfill gas near a landfill in Akron, Ohio, USA	USEPA (1991)
1987	Explosion of a house due to gas migration in Pittsburgh, Pennsylvania, USA	USEPA (1991)
1994	Fire injury to a woman by methane explosion in a park built over an old landfill in Charlotte, North Carolina, USA	Charlotte observer (1994)
1999	A girl was burned on an area was reportedly used as an illegal dumping ground in Atlanta, USA	Atlanta journal-constitution (1999)
2010	Fire accident in Madison county Landfill, Lincoln town, USA	cnycentral.com (2010)
2011	Fire accident in Veolia landfill, USA	News-sun (2011)
2011	Fire accident in Kildare, Republic of Ireland (Southern Ireland)	(Belfasttelegraph 2011)

chance of spontaneous combustion (USFA (U.S. Fire Administration) 2001) due to the higher temperatures in these months leading to spontaneous combustion and hot, smoldering substance like discarded matches and cigarettes. Apart from spontaneous combustion, fire can be rekindled from previous fire, flammable material, and inadequate control of open fire.

Landfill gases migrate from the landfill either above (atmosphere) or below ground (groundwater, voids in soil) contaminating air, soil and groundwater and accumulation of gas which may explode or create fire hazard. Flammable gases generated in land fill include methane, ammonia, hydrogen sulfide, non methane organic compound (NMOCs).

Underground fires in landfills are referred to as deep-seated fires involve materials that are months/years old. Deep seated fires are capable of creating large voids in the landfill and cave-ins of the landfill surface. They produce flammable and toxic gases and damage liners and LFG collection systems (FEMA 2002). These are problematic due to the difficulty in detection, control and extinguishment. The following factors (Margaret 2004) or their combinations are the reasons for underground fires: (1) poorly engineered/maintained cap, (3) inadequate profiles of the capping, (4) inadequate compaction of wastes, (5) settlement of waste, landslides, cap erosion, (6) inadequate thickness/material of intermediate capping, (7) damage to LFG collection system, (8) poor maintenance of the LFG control system, (9) insufficient gas well adjustments during operation, (10) extracting more LFG than was being produced, (11) deteriorating seals on the gas wells, (12) too wide spacing of gas wells.

Oxygen continuously introduced into the waste due to infiltration via the exposed edge can start oxidation processes or aerobic decomposition thereby causing spontaneous combustion of certain waste components. Hence, the signs of subsurface fire, like smoke, smell may take long time to be detected at the surface. Hence the deep seated fires can be confirmed by (FEMA 2002; Margaret 2004): (1) substantial settlement within short period of time, (2) smoke or shouldering odour from the landfill or gas extraction system, (3) carbon monoxide in excess of 1,000 ppm, (4) combustion residue in extraction wells/headers, and (5) increase in temperature in the gas extraction system.

Management plans for landfill fire include (Margaret 2004): (1) prohibition of deliberate burning, (2) prohibition of smoking on site, (3) inspection of incoming loads, (4) control of deposition of waste, (5) good compaction and cover, (6) maintenance of fire fighting extinguishers/equipment, (7) maintenance of adequate water supply, (8) keeping protective clothing and breathing apparatus at landfill site.

The site of a landfill *Love Canal* in New York used for the disposal of about 21,800 tons of chemical wastes was covered with soil in 1953 followed by construction of houses and an elementary school adjacent to the landfill. The area was later declared as Emergency Declaration Area (EDA) followed by evacuation of the residents in the surrounding area due to increase in visible seepage, noxious smells and chemical contamination in 1978–1980. The studies in the area revealed and confirmed birth defect (DOH 2008).

11.4.4 Safety Issues in Incinerator

The safety problem while operating incinerators rises due to a presence of hazardous substances. Depending on the waste incinerated, the operating location could be odorous, slippery, and dusty. The location could also be infectious if infectious wastes are being incinerated. The operators of the incinerators are continuously exposed to smoke and high temperature. The incineration locations

Fig. 11.17 Object on the way to fire extinguishers

need to have all precautionary measures for the possible sparks, explosion, spread in of fire. Hence, is the precautions taken to reduce or prevent the likelihood of death, injury, or property damage due to fire. Conventionally fire is classified into fine types:

- **Class A**: Fires due to burning of solids other than combustible metals.
- **Class B:** Fires involving combustible or flammable liquids.
- **Class C:** Fires involving energized electrical equipment.
- **Class D:** Fires involving combustible metals.
- **Class K:** Kitchen fires.

Fire is extinguished by Active Fire Protection (AFP) or Passive Fire Protection (PFP). PFP is achieved by compartmentalization prior to use AFP Fig. 11.17.

AFP is achieved by automatic fire sprinkler systems and other fire extinguishers.

The major types of fire extinguishers are:

- **Water extinguishers:** Water as an extinguisher is suitable for class A fires and not suitable for class B, C and D.
- **Dry chemical extinguishers:** These are useful for either class BC or class ABC fires. They leave a blanket of non-flammable substance on the extinguished substance which prevents the likelihood of re-ignition. 'Class BC' fire extinguishers contain potassium or sodium bicarbonate. 'Class ABC' fire extinguishers contain ammonium phosphate.
- **Carbon dioxide extinguishers:** These are used for class B and C fires.
- **Sand/metal/metallic salt Extinguishers:** These are used for class D fires.

The major chemicals used are-

- *Sodium chloride*—used for metal fires involving sodium/potassium alloys, magnesium, sodium potassium, uranium and powdered aluminium.
- *Powdered copper metal*—used for fires involving lithium and its alloys.

– *Graphite based powders*—used for lithium fires.
– *Sodium bicarbonate based dry agents*—used for fires with most metal alkyls, pyrophoric liquids that ignite on contact with air.
– *Sodium carbonate based dry powders*—used generally for Class D fires.

- ***Halotron I extinguishers:*** These are suitable for telecommunications equipment, computer rooms, and electronics.
- ***Water mist extinguishers****:* These are suitable for Class A fires where a possible Class C hazard exists.
- **Non-magnetic fire extinguishers**: These are used for Nuclear Magnetic Resonance Spectrometers (NMRS) or Magnetic Resonance Imaging (MRI) machines.

The pressure of fire extinguisher shall be at the recommended level. The extinguisher should not be blocked by objects that could interfere with safety operations during emergency (Fig. 11.17). The nozzle should not be obstructed. There should not be leaks, rusts, dents, and chemical deposits. The pin and tamper seal should be intact.

Fire alarms are another important security device that helps to protect life and property from fire accidents which are essential at structures where waste is stored/handled/disposed.

Incinerator operators are exposed to chemicals, dust, acid and micro organisms (Fleming et al. 2000). Hence operator shall ensure proper personal protective equipment and dress as shown in Fig. 11.18.

The potential health hazards in landfill sites can arise from generation of methane gas and carbon dioxide produced from the waste. People at a landfill site are also exposed to micro organisms which are spread during the handling of waste. Other health impacts due to landfill include increase in risk of low birth weight, birth defects, cancers (Vrijheid 2000; WHO 2007).

11.5 Work Permit System

Work permit (Table 11.4) system is a system within an organisation which provides identification, control and review of hazards within any work environment. Examples where safe work permits are required include: (1) entry to a confined space, (2) work in or around confined spaces, (3) working at heights, (4) excavation, and (5) hot work.

The advantages of permit to work system are: (1) ensures suitable people are authorised, (2) provides clarity about the hazard, (3) specifies the precautions, (4) ensures the person in direct charge of the facility about the work under progress, (5) provides a system of continuous control, and (6) provides formal handover and hand back procedure.

Before issuing a work permit, the issuer and recipient should consider all potential hazards such as material hazards, pressure, temperature, fumes, electrical

Fig. 11.18 Personal protective equipment in common biomdial waste treatment facility

power, mechanical energy, hazardous areas, height, radioactive sources, explosive materials, restricted space field vision, and any other. The work permit should also specify the precautions, such as: (1) isolation, (2) decontamination, (3) working in confined spaces, (4) hot work, (5) working at heights, (6) excavation and building work, (7) work on high voltage equipment, (8) personal protective equipment, (9) provision to notify pertinent persons when work commences/completed, and (10) any other special precautions.

The procedure for obtaining a permit includes a written request followed by a duly filled safety permit by the issuing authority. Permits should be in printed forms in triplicate, serially numbered and different colour code may be adopted for different types of permits. While copy will be retained by the issuing department, yellow copy will be issued to concerned department and returned to safety department. Red copy will be issued after completion of job signed by the concerned department and returned to the issued department.

Work permit systems are adopted in electrical plants, electrical transmission/distribution/utilization system to ensure that the plant/equipment/circuit is switched off and is dead earthed before commencing the work.

Table 11.4 Sample permit to work

HAZARDOUS WORK PERMIT **(To be used where no other permits apply)** **Job Location: Building: _________ Dept: _________ Location: ___________** **Job Description:** **Work to be done by: ____** **Date Work is to begin: __________ Completion Date: _______ Time: ________** **Nature of Hazard:** **Precautions Required:** **Signatures of Exposed Employees:** ________________________________ ________________________________ **(Date)** **(Date)** ________________________________ ________________________________ **(Date)** **(Date)** **Supervisor: ________________________________** **Signature (date)** **Manager: ________________________________** **Signature (date)** **Safety Representative: ________________________________** **Signature (date)**

The work permit is withdrawn and cancelled after the completion of work. For example, a circuit breaker is switched on and supply restored only after cancellation of the work permit. The list of safety documents in industrial works are given in Table 11.5.

Special work permit and safety procedures are issued for "live line maintenance work". Tables 11.6 and 11.7 give two sample safety clearance notices. Table 11.8 gives a sample limited work permit. Table 11.9 gives a sample permit to test.

The clearance procedure in general is intended to meet the following principle requirements in relation to potentially dangerous jobs:

a) Protection of men at Work,
b) Protection of equipments, and
c) Designation of abnormal.

The above requirements can be achieved by providing safe working conditions, essential information and guidance to the men at work, checking arrangements to ensure reliability of the highest order, etc. through the use of the following:

a) Permit to work,
b) Sanction for test,
c) Station guarantee,

Table 11.5 List of safety documents

Title and description	Issue by/when?	To work
Safety clearance Notice (SCN) before energizing	Site manager before energizing a plant/circuit	Contractors
Permit to work (PTW)	Site manager before carrying out electrical work: repair/ maintenance	Persons who will work/supervisor
Limited work permit (LWP)	Site manager/station in charge before test	Testing engineer
Permission to test (PFT)	Site manager/station in charge before test	Testing engineer
Handing over document (HOD)	Manager civil manager erection manager testing site in charge	Manager erection,manager testingmanager commissioningowner's plant manager
Safety documents for site work	Manager safety or site manager	All concerned

Table 11.6 Area/room safety clearance notice (Format I)

Division: ________________________/______________________

Project No/Description: ____

Room No(s): ____

Brief Description of Project: ____________________________________

I confirm that so far as is reasonably practicable all rooms, doors, fixtures and fittings in the above areas are free from the following hazards:

- ☐ Biological Hazards
- ☐ Dangerous Substances and Substances Hazardous to Health
- ☐ Radiological hazards
- ☐ Physical Hazards

and that the appropriate checklist(s) and action sheet(s) have been completed.

Name: ____________________________ Tel No: ______________

Dept/Division: ____

Date: ____

Signed: ____

This form should be attached to the door of the appropriate room and the room secured.

Comments:

____

____

____

____

____

Table 11.7 Area/room safety clearance notice (alternate to format I)

Centre contact	**Room**	**Centre contact**	**Room**
Estates / Contractor	**Ext / Phone no.**	**Helpline**	**Estates Manager**
Room No.		Room Title	
Description of work			
Hazards	Chemical	Equipment	Computers
Access	Biological	Laser	Pressure
Temperature	Radiation	Noise	Glassware

Actions	By whom	Completed

Sketch of room including actions: (indicate usual entrance)

Additional comments		
Actions completed	by	on
Work began	by	on
Comments		
	Date of work completed	

d) Self protection tag, and
e) Danger notices.

As a responsible person needs to be designated for controlling the issue and cancellation of clearances under various conditions and safe and expedition's execution of works there under. The authorized person may further authorize assistants for issuing and cancelling clearance (e.g., operator for (1) making and cancelling of permits to work, sanction for test, plant guarantee, (2) authorizing work under self protection tag and danger notice subject to such conditions as may be necessary to ensure reliability and security of the highest order.

When work is to be done on any electric apparatus which can be made live from more than one stations or sections thereof, clearances should be obtained from the senior authorized persons of each of the stations/section involved before commencing work. Before issuing clearance each of the operators concerned should

Table 11.8 Sample limited work permit

Name of the Plant:______________________

LWP No.________________________________ **Date:_____________________**

LIMITED WORK PERMIT

Permission is given to carry out following work in specified zone on specified date and time

Name:
Plant:
Zone:
Equipment:

Nature of Work:

Actions completed	by	on	
Work began	by	on	
Comments			
		Date of work completed	

check counterparts in other stations/sections concerned that all precautions have been taken.

11.6 Safety Education and Training

Organizations are responsible for ensuring that all personnel are properly trained before they begin work in a waste handling site and that they receive additional training when new hazards or procedures are introduced.

In addition to general Environment Health and Safety (EH&S) training, all employees, must receive job-specific training on the following topics:

- Location and content of the safety manual
- Physical, chemical, biological, laser and radiation hazards in the work area, including signs and symptoms of exposure and allowable exposure limits
- Location of references describing hazards and safety practices associated with laboratory materials (e.g., material safety data sheet (MSDS), merck index, bio-safety in microbiological and biomedical laboratories, etc.)
- Protective measures employees should take to avoid exposure or injury, as specified in the laboratory's Standard Operating Procedures (SOP)
- Procedures for responding to emergencies (fire, chemical spill, severe weather, etc.) as outlined in the emergency action plan

Table 11.9 Sample permit to test

Name of Plant

Permit to test No.: **Date:**

PERMIT TO TEST

Permission is hereby given to test following:

Plant:______________________
Zone:______________________
Equipment:__________________
Name of Test:________________

Following plant will be withdrawn from normal operation for facilitating above test:

……………………………………………………………………….

Test schedule:
Start of test:____
Planned date of completion:_____________________________
Safety precautions:

To
…………………….
…………………….
…………………….

Name and Signature of Site In charge

Acknowledgement:

Received PTT No.:…………………… **Dt**………………………

Name, Organization and signature

- Methods to detect the presence of contamination or the release of chemical, biological and radioactive materials
- Procedures for obtaining medical care in the event of exposure/injury
- Proper waste management and disposal procedures
- Proper recordkeeping

Departments and/or supervisors must maintain safety training records for all personnel. Acceptable records include site-specific training forms, safety training history, training certificates, and/or copies of employee “training history” from the EH&S learning centre. Employee training records must be retained for at least one year after end of employment.

11.7 Safety Promotion and Publicity

Safety promotion is the process applied at a local, national and international level by individuals, communities, governments and others (including enterprises and nongovernmental organizations), to develop and sustain safety. This process includes all efforts agreed upon to modify structures, environment (physical, social, technological, political, economical and organizational) as well as attitudes and behaviours related to safety.

Safety promotion and publicity can occur during: (1) before the event, (2) the actual event (3) after the event. Promotion can occur at these levels: (1) group, (2) organization, (3) community, (4) nation, (5) world.

An industrial plant, a trade union and a religious community are examples of what makes up the framework for co-operation in a secondary group. Here, we define the secondary group—organization—at its own level. The work method concerning health is often different compared with the primary group. In other circumstances the boundary between the primary and secondary group can be unclear. However, work within the group need not to be the result of influence from outside or organized programming but can be the product of a voluntary undertaking.

An effective training program can reduce the number of injuries, property damage, legal liability, illnesses, workers' compensation claims, and missed time from work. Some of the common methods in safety publicity are: (1) handouts, (2) events (essay writing, skits, etc.), (3) posters, (4) e-mails, (5) short message service (SMS), (6) stickers, and (7) training.

11.8 Hazards Encountered in Hazardous Waste Handling and Disposal Sites

Hazardous waste handling and disposal sites will have hazardous substances which are toxic and corrosive. Chemicals exercise toxic effects on humans by gaining way into the tissues and cells. The major routes of contact are inhalation, absorption through skin, and ingestion. Entry may also occur through mucous membranes of the nasal or eyes passages. Exposures may be chronic or acute, may be temporary or may permanent.

Inhalation is the potential exposure route of concern in hazardous site. The respiratory system will quickly absorb of oxygen into the blood stream from where it is distributed to the other organs of the body. The toxic chemicals when inhaled will be absorbed and distributed to other parts of body. Particles will coat the lung tissues, affecting lung function.

Absorption by epithelial tissues of skin and mucous membrane may directly injure the skin or may pass through the skin and transported to various organs. Absorption by epithelial tissues is enhanced by wounds/heat/moisture. Chemicals can dissolve in the moisture of eye and be carried through the bloodstream.

Personal habit like chewing/drinking/eating/smoking at work place may provide route to entry of toxic substance and hence should be prohibited.

The potential causes of fire and explosions on hazardous waste sites include: (1) chemical reactions bet non-compatible material, (2) ignition of explosive/flammable material, (3) ignition of substance due to oxygen enrichment, (4) agitation of shock/friction sensitive compounds, and (5) sudden release of substance under pressure.

Another hazard in hazardous waste disposal facility is oxygen deficiency. The oxygen content of normal air is about 21 % and humans experience physiological effects (like impaired attention, judgment, and coordination and increased breathing and heart rate) when oxygen concentrations in the air falls below 16 %. Oxygen deficiency may also occur due to displacement of another gas, due to consumption of oxygen. Confined spaces in waste management and disposal area are vulnerable to oxygen deficiency and, hence, workers must be trained properly about safety precautions to be taken in confined spaces.

In addition to the confined spaces hazardous waste disposal site also pose threat to human life due to ionization radiation. Some atoms called radio isotopes are radioactive and undergo a spontaneous decay process, emitting radiation till they reach a stable form. The rate of radioactive decay is measured in half-lives (the time required for half the atoms in a sample to decay to another form). Each isotope has its own half-life. The radioactive isotopes found in radioactive waste emit three types of penetrating ionizing radiation—alpha (α) and beta (β) particles and gamma (γ) rays.

α particles are positively charged ions that propel from the nucleus of atoms at around 10 % of the speed of light.

β particles are negatively charged particles that move at velocities varying from 30 to 99 % of the speed of light.

γ radiation is a type of electromagnetic energy wave.

Radiation exposure damages cells, tissues, organs and organisms. The effects could be somatic or genetic. Somatic effects are those that cause damage to the exposed individual and include anemia, fatigue, and loss of hair, cataracts, skin damage, and cancer. Genetic effects include inheritable changes resulting from mutations in reproductive cells.

11.9 Electrical Hazards

Electrical wires/cables pose a danger of shock or electrocution to workers. Electrical equipment at site is also a hazard to workers if proper precautions are not taken. Low voltage equipment with ground-fault interrupters, and water-tight, corrosion-resistant connecting cables will minimize hazards. Capacitors used onsite may retain a charge and shall be earthed before handling. Weather conditions should be monitored so that work can be suspended during thunder storms, to avoid lighting hazard.

11.10 Heat Stress

Heat stress is the main hazard for people wearing protective cloths in the waste management site. The protective cloths that serve to shield the body from chemical exposure limit the dissipation of body heat and moisture. Depending upon the ambient conditions and the work performed, heat stress can develop rapidly. It can pose danger to the workers health. Heat stress can cause rashes, cramps, discomfort, and drowsiness. Continued heat stress can result in heat stroke and death. Avoiding overprotection, training and frequent monitoring of personnel wearing protective clothing, judicious scheduling of work and rest periods, shade ventilation and frequent replacement of fluids will provide protection against this hazard.

11.11 Cold Exposure

Cold injury (frost bite and hypothermia) and weakened ability to work are dangers at low temperatures. People should wear appropriate clothing, have warm shelter available, schedule work and rest periods, as well as monitor workers physical conditions.

Landfill cell building will be affected and moisture content will build up within landfill. Snow makes navigation difficult, local bodies usally request residents to ensure the garbage does not get covered by snow (as shown in Fig. 11.19). Keeping garbage on snow bank or behind the snow bank will make pick up difficult. Collection delays may occur during snow fall due to unsafe road conditions (Fig. 11.20). As a result, waste may be collected later than usual or next day. Local bodies request the residents of towns/cities to place waste bins in morning instead of the night before collection as waste bin can get covered by snow.

11.12 Noise Hazard

On-site activity in closeness to heavy equipment and machinery can create a noise environment that is hazardous (Das et al. 1999). Wearing ear plugs, scheduling work an rest period are some of the measures that can help reduce noise. Providing absorbents in the walls, acoustic design, false sealing with absorbents, proper lubrication of machineries, proper maintenance of machines, providing proper shock absorbers will also help reducing noise.

Fig. 11.19 Positioning of garbage bins during snow fall

Fig. 11.20 Transportation may get affected during snow fall due to difficulties in vehicle movement

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Chapter 12
Environmental Issues

Almost all anthropogenic activities will have impact on the environment and so as waste management. Even though proper waste management does reduce the magnitude of impact, it will not eliminate the impact totally. The assessment of the environmental impacts is important to protect environmental settings. The impact on environment can occur at any stage of waste management.

The word "environment" is new in several languages. In French, its origin comes from twelfth century verb "environner". New words were created in other languages: "Umwelt" in German "Parisara" in Kannada, "Paryavaran" in Hindi, "Milieu" in Dutch, "Ambienta" in Italy, "Miljö" in Swedish, "Medio ambiente" in Spanish, "Meioambiente" in Portuguese, "Kankyo" in Japanese, "Al.biah" in Arabic, etc. About 40 years ago, the world started realizing new challenge to modern society. The term "environment" which means one's surrounding in dictionary took several dimensions. Environment can be a space adjacent to a microbe, or neighborhood of dwelling, or the city where we live or the entire planet along with space surrounding it.

Associated with environment the word pollution took importance too. Late eighteenth as well as early nineteenth centuries saw the most important changes in agriculture, manufacturing, mining, production, and transportation. The industrial revolution became a turning point for new changes the major one is waste and associated pollution. Improper practices with respect to waste management lead to pollution, resource degradation and health of humans/animals. The late eighteenth and the early nineteenth centuries produced metal, machinery, and textile and associated wastes. The current century is generating a variety of waste the impact of which is still not fully understood. Informal practices in WEEE recycling resulted in release toxic metals and persistent organic pollutants (POPs) into the environment (Wong et al. 2007) many of which are carcinogens. Studies have revealed that the environmental and health problems in China (Bi et al. 2007; Deng et al. 2007; Leung et al. 2006; Li et al. 2008; Luo et al. 2009; Wu et al. 2008; Zhang and Min 2009; Zhao et al. 2009) and so as many other countries due to improper waste disposal.

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A high rate of urbanization in the African countries has lead to inefficient MSW management policies. Dakar, home to nearly 3 million people, produces approximately 4,00,000 t of garbage per anum and in this West African town, every street is lined with waste and overflowing refuse bins which go un-emptied for many days. About 3,000 t mercury-bearing wastes originating from Taiwan, disable video films from Korea and imported unusable shoes were dumped in Cambodia (MoEKoC and UNEP 2006).

Life cycle assessment (LCA) has become an emerging tool to measure the impacts of anthropogenic activities on environment (Pennington et al. 2004; Rebitzer et al. 2004). As per Christensen et al. (2007) LCA is the major tool for decision making used by policy makers. One of the benefits of LCA is to identify and quantify environmental impacts of various waste management technologies (Buttol et al. 2007). Only limitation of LCA or any other study for that matter is that studies have to be conducted and reported impartially.

Environment impact assessment (EIA) has been the preferred tool in past many years for mega projects including waste management. It is often the duty of EIA preparing agency to get statutory permits and hence the base line data and impact projections are usually manipulated. The EIA made by consultants is often misleading and hides facts. Consultants often prepare reports in favor of clients and hence obviously cannot give a negative report which may ultimately cause damage to investor/project proponent.

Waste handling/disposal facilities should avoid impact on environment through a combination of: (1) selection of proper site, (2) proper design of facility, (3) energy efficiency, (4) process modification, and (5) application of emissions control techniques. The prevention and control of pollution depend on: (1) regulatory requirements, (2) magnitude of the source, (3) location of the emitting facility relative to other sources, (4) location of sensitive receptors, (5) existing ambient air quality, (6) technical feasibility and cost effectiveness.

12.1 Impact on Air, Water and Soil

Solid waste management and handling is associated with both positive and negative impact on environment. While waste management has positive impact by removing accumulated waste it is often associated with negative impacts as depicted in Fig. 12.1 and Table 12.1. A proper study of environmental setting will be required to forecast possible impact in worst scenario and prepare environmental management plan.

Air pollution sources can be categorized into point sources, fugitive sources, and mobile sources. Facilities located in ecologically sensitive areas (like national parks, sanctuaries, monuments), should ensure low pollution by: (1) relocation of facility, (2) use of cleaner fuels/technologies, and (3) use of proper pollution control measures. Uncontrolled LFG migration from a landfill poses a threat not only by GHG emission but also to human health and local environment. LFG can

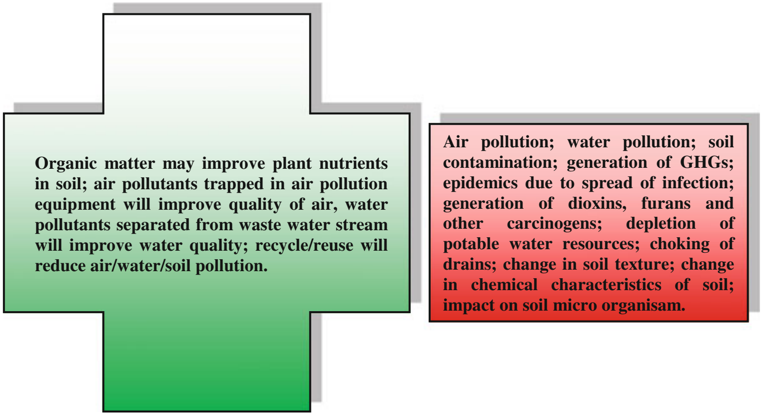

Fig. 12.1 Positive and negative aspects of solid waste management on air/water/soil

cause explosion or fire due to build up of LFG in buildings located near landfill sites as it is heavier than air and hence collect in sewers and manholes. Further gases from landfill can cause asphyxiation. Hence proper care is required during construction and operation of landfills.

Emissions from waste processing and disposal often lead to disposal of POPs. Polychlorinated dioxins and furans (PCDD/Fs) and, polybrominated dioxins and fFurans PBDD/Fs concentrations in ambient air around Guiyu, China varied from 64.9 to 2,365 pg/m^3 and from 8.1 to 461 pg/m^3, respectively due to WEEE dismantling activities (Li et al. 2007a, b).

The presence of waste pickers in disposal sites will pose major impact on the operation of the sites. Waste pickers pose safety hazard to themselves and others working in landfill reducing productivity and interfering with operations as well as tipping face and starting fires. Such activities cause serious air pollution. To overcome such problems, a landfill located in San Mateo of the Philippines, employs the inhabitants of nearest squatter community for work at the site (Lars and Gabriela 1999). Incineration and open burning will lead to emissions of water vapor, carbon oxide, carbon dioxide, sulphur oxides, nitrogen oxides, silicates, ash, soot, metal elements, oxides of metals, salts, volatile organic compounds (VOC), hydrocarbons (HC), dioxins, furons, polychlorinated biphenyls, polycyclic aromatic hydrocarbons. Particles from waste combustion include particulates with an aerodynamic diameter lesser than 10, 5, 2.5 microns and ultrafine particles. Further combustion and handling of waste during combustion lead to generation of transport–related emissions, noise, odor, bottom ash, fly ash, pests, dusts and spores.

Waste management emits a number of substances in small quantities at extremely low levels (Johnson and DeRosa 1997). Waste management workers have shown to have high incidence of accidents as well as musculoskeletal problems (Lesley 2003). Epidemiological studies have demonstrated that particle

Fig. 12.2 Damage to vegetation due to waste dumping and transportation

exposure will result in acute health effects like increased mortality, cardiovascular and respiratory morbidity (Dockery and Pope 1994; Katsouyanni et al. 1997). Effects will be more severe in children, elderly, and those with pre-existing cardiovascular disease or asthma (Zanobetti et al. 2000). Chemical landfill in Kaergaard, Denmark resulted in release of 280,000 t of chemicals and pharmaceuticals in pits sited in the beach dunes (WHO 2007). Emissions from solid waste disposal facilities can be avoided and controlled by: (1) proper stack height, (2) water sprinkling for dust suppression, (3) leak detection and repair (LDAR) program, (4) collection of vapours and consequent treatment of gas stream (5) use of floating roofs above storage tanks in order to reduce volatilization by eliminating the space in conventional storage tanks.

Emissions from vehicles which include CO, NO_X, SO_2, PM and VOCs con be controlled by: (1) using fuel efficient vehicles, (2) engine maintenance programs, (3) adopt safe speed limits, (4) replacing older vehicles with newer, more fuel efficient vehicles, (5) installing and maintaining emissions control devices like catalytic converters, (6) use of clean/eco-friendly fuel, and (6) implementing a regular vehicle maintenance and repair program.

Waste handling facilities should avoid, minimize, and control liquid effluents by: (1) adopting recycle/reuse within the facility, and (2) liquid waste treatment.

Figures 12.2, 12.3, 12.4, 12.5 and 12.6 shows photographs depicting impact on environment due to haphazard disposal of waste.

In order to reduce pollution of storm water following principles/precautions should be applied: (1) avoiding/minimising contact of runoff with waste, and (2) collect and treat contaminated runoff.

The soil contamination is one of the major impacts due to solid waste disposal as the wastes come in direct contact with soil. 500 metric tons of toxic waste dumped during 2006 in the city of Abidjan, Ivory Coast resulted in symptoms of poisoning of thousands within few days due to presence of sodium hydroxide, phenols, hydrogen sulphide, mercaptans, hydrocarbons as well as other chemicals used in cleaning of oil transporters' tanks. The episode resulted in 8 deaths, hospitalization of dozens and around 100,000 medical consultations (Bohand et al. 2007).

Fig. 12.3 Damage to soil and vegetation due to industrial waste dumping

Fig. 12.4 Damage to soil due to improper industrial waste disposal

The lead concentration of bottom ash of WEEE recycling units of New Delhi varied between 3,560 and 6,450 mg/kg (Brigden et al. 2005). Considering high impact of WEEE processing in India and China, Alejandra et al. (2010) is of the opinion that there is an urgent need for better monitoring as well as control of the informal recycling activity in China and India.

Collection of waste is always associated with vehicle movement and associated maintenance which results in generation of air pollutants. On the positive impacts include possible improvement of plant nutrients in soil and recycle/reuse will reduce air/water/soil pollution.

Fig. 12.5 Air pollution due to burning of street sweepings to avoid hauling expenditure by waste handling agency

Like any other activity waste management and disposal creates of job and livelihood making positive impact on the society.

Populations living near incinerators are greatly exposed to chemicals by inhalation of contaminated air, dermal contact with contaminated soil, consumption of contaminated food and water (Franchini et al. 2004). Vianna and Polan (1984) as well as Goldman et al. (1985) observed augmented occurrence of low birth weight among the people around the Love Canal site of the USA. A similar augmented occurrence of low birth weight babies was observed among those living in a radius of one km of the Lipari Landfill, New Jersey (Berry and Bove 1997). Low birth weights as well as neonatal deaths were observed at a waste disposal site in California (Kharazi et al. 1997).

Collapse of Mobeni landfill (near Durban in South Africa) led to an odour problem in neighboring community and Uganda's Mpewere landfill started in 1995 became open dump within one year (Lars and Gabriela 1999). Similarly land fill at Kampala city council was not operated properly due to small operational budget and deficient local managerial expertise to operate the landfill (Lars and Gabriela 1999). Such scenarios would lead to impact on the environment and health of the community which would have definitely not foreseen.

12.2 Impact on Flora and Fauna

Impact on flora and fauna depends on ecological sensitivity around the waste handling and disposal site. The improper biomedical waste disposed would affect health of fauna in urban as well as non-urban (like forest, rural, savanna etc.,) settings. The major impact on flora and fauna is given in Fig. 12.7.

Animals often are attracted by solid waste dumped on the ground (Fig. 12.8) as municipal solid waste often comprises of food waste. Food smeared to plastic covers has been a reason for choking of digestive track leading to death in stray

Table 12.1 Summary of impact on environment due to solid waste management

Activity	Impact	Air Pollution	Water Pollution	Soil Pollution	Noise Pollution
Storage	Generation of Dust	✓	✓	✓	
	Generation of fume	✓	✓	✓	
	Material recovery	✓	✓	✓	✓
	Movement of bins and dropping of waste	✓	✓	✓	✓
Collection	Movement of vehicles	✓	✓	✓	✓
	Material recovery	✓	✓	✓	✓
	Vehicle maintenance	✓	✓	✓	✓
	Degradation during collection	✓	✓	✓	
	Activities of waste pickers	✓	✓	✓	
Transfer and transport	Operation of machine	✓	✓	✓	✓
	Movement of vehicles	✓	✓	✓	✓
	Material recovery	✓	✓	✓	✓
	Vehicle/machine maintenance	✓	✓	✓	✓
	House keeping	✓	✓	✓	✓
Reuse/recycle	Operation of machine	✓	✓	✓	✓
	Movement of vehicles	✓	✓	✓	✓
	Material recovery	✓	✓	✓	✓
	Cleaning of recyclable material	✓	✓	✓	✓
	Composting	✓	✓	✓	
	Material processing	✓	✓	✓	✓
	Waste to energy	✓	✓	✓	✓
Disposal	Waste dump	✓	✓	✓	✓
	Animal feed	✓	✓	✓	✓
	Thermal conversion	✓	✓	✓	✓
	Land fill	✓	✓	✓	✓
	Geological disposal		✓	✓	
	Ocean Dump		✓		

animals that feed on municipal solid waste. Further, birds have been major dependents on solid waste for their food in dump sites and sanitary land fill sites. Irrespective of developed or developing country the birds often feed on food waste thrown with municipal solid waste. The solid waste that enters food chain could be detrimental if the food is contaminated with toxic or infectious material.

Further cities near sensitive location like sanctuaries/forest would often throw waste in outskirts which may affect the health of wild animals which feed on the waste. The waste thrown into water bodies would affect the aquatic ecosystem. Composting and waste handling would release bio-aerosols containing bacteria or fungal spores.

With growing meat consumption the production of slaughterhouse waste is often determined by market forces. The meat production may generate infectious waste (Figs. 12.9 and 12.10) that requires precaution, treatment and disposal. Bangalore in India has approximately 3,000 chicken shops spread across the city wherein the birds are killed in front of consumers. Bangalore with population of approximately ten million needs meat of about 600,000 birds/day and the waste generated is mixed with municipal solid waste.

Fig. 12.6 Waste floating on river

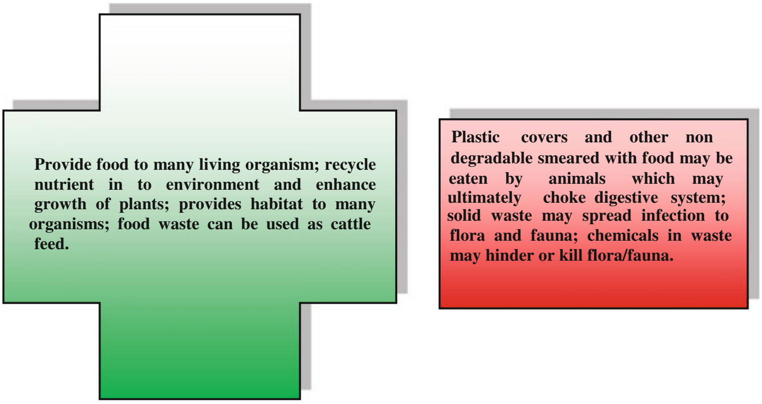

Fig. 12.7 Positive and negative aspects of solid waste management on flora and fauna

In many countries animals are slaughtered only when they are not useful for other purposes. The examples include oxen which are used for transportation and ploughing carts will be slaughtered when they become old and weak. The cows are slaughtered when they stop producing milk. Lack of care while transporting animals results in weight loss and cruelty to animals and. Many of the animals slaughtered

Fig. 12.8 Cattle feeding on waste

Fig. 12.9 Feathers disposed haphazardly

suffer from malnutrition, diseases and parasitic infestation (CPHEEO 2000). Disposal of slaughter house in many countries would end up in spreading disease not only to domestic animals but also to wildlife. The practice would also result in transfer of disease from animal to humans. Diseases which occur normally in animals that are transmitted from animals to people (e.g. Swine flu) are called zoonoses and there is increase in occurrence of zoonosis epidemics in the present century.

Transfer of epidemic and endemic diseases occur across countries as pathogens are transmitted by the environment. Interactions of zoonotic infections are illustrated in Fig. 12.11.

Zoonotic pathogens cause gastrointestinal diseases like diarrhoea and other sickness like leptospirosis and hepatitis. About four billion cases of diarrhoea happen every year, resulting in approximately two million deaths and intestinal worms affect more than a billion persons all over the world (Cotruvo et al. 2004). Due to a lack of data it is difficult to determine the complete extent of the illness due to zoonotic pathogens.

Fig. 12.10 Slaughter house waste

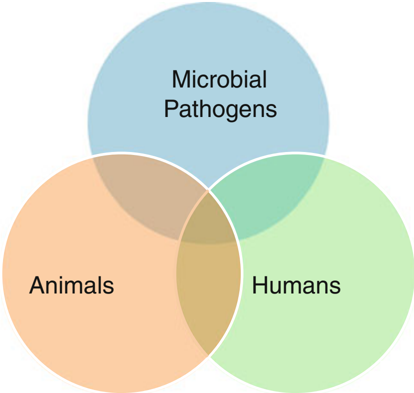

Fig. 12.11 Interaction between microbial pathogens, animals and humans

Driving forces of emerging zoonotic pathogens is significant and include: (1) changing life style patterns, (2) shifting eating habits, (3) changing urban topography and demography, (4) efficiency of sanitation and waste management, (5) immunity of individuals for diseases, (6) climate change, (7) disasters, (8) increasing use of antibiotics by animals and humans, (9) density of domestic pets, (10) ecologic disturbance, and (11) international trading of animals, and animal products.

As discussed earlier waste not only affects the flora and fauna within a city it would also affect wildlife. The waste dumps or bins could be approached by wild lives (Fig. 12.12) in search of food. The animals including birds would suffer by eating plastic covers used to pack food as they are attracted by smell.

In addition to other wastes, radioactive waste also sometimes finds its way to MSW. The episode that occurred in Delhi due to selling of waste with radioactive material led to death of one person (**Box 12.1**). If the same waste was dumped in municipal waste along with other waste the impact on animals would not have come to notice at all.

Fig. 12.12 Wild life and waste litter

Box 12.1 Impact of improper disposal of radioactive material in Delhi (India)

Disposal of radioactive waste in many countries is unscientific affecting health of people. In April 2010 a scrap dealer and his employees were exposed to the radioactive Cobalt-60 present in the old Gammacell model 220 they brought from Delhi University (AERB 2010). As a result of exposure hair of exposed people started falling and later skin started showing signs of decay. The incident also resulted in death of one person working with scrap dealer.

Many studies have been done on impact of waste on forest. Foin et al. (1977) studied the impacts of visitors on Yosemite National Park, California. As per Cole and Mwanza (1991) discarded plastic causes the deaths of nearly two million seabirds and about 100,000 marine animals every year. Studies conducted by Jain and Kuniyal (1994) in the Himalayan region revealed that religious and recreational tourists have increased solid waste in the region. The arrival of migrant birds reduced noticeably in the past few years in Kadalundi bird sanctuary in India due to waste dumping. The tourism can generate great quality of wastes and associated problems. Solid waste management has become problem in many national parks throughout the world.

Solid waste generation in some tourist places of the Himalayan region is nearing that of some metropolitan cities of India. The native villagers construct stalls every year to fulfil the requirement of visitors to Valley of Flowers as well as Hemkund Sahib. Valley of flowers national park is meant for the conservation and study of Himalayan flora. It became a national park in 1982 after which restrictions were imposed on livestock grazing. The valley has flora of over 600 species in an area of about 2,500 ha. Approximately 29 t of solid waste is generated during four month tourist season every year along a distance of about 19 km. As per Kuniyal et al. (2003), nearly 288 g waste is generated/visitor/day compared with the Indian average of 350 g capita/day. Treks (stretch between places covered by walk) and trek stalls are major places where waste is generated. About 51 % of the waste generated in trekking region will be produced in trek stalls with glass bottles, plastic and metal contributing to non-biodegradable waste (Kunival et al. 2003).

Piles of non-biodegradable waste in 19 km dumped over the last three decades with an annual traffic of 600,000 visitors were cleared with local support collecting 44 t of solid waste in 14,000 bags. Along with non-degradable waste, tons of mule dung generated by about 500 mules which helped visitors was also collected. The recyclable objects in waste was transported to Delhi for recycling.

Apart from mountains, ocean ecosystem is also suffering due to solid waste. Anthropogenic waste which is deliberately or accidentally released to sea and become afloat is called marine debris, or marine litter. Deliberate disposal of wastes into sea is called ocean dumping. These debries accumulate at the centre of gyres and coastlines. The debris washed aground is called beach litter or tide-wrack. Anthropogenic activities have led to a major decline of the world's biological diversity, and have accelerated due to human impacts (Lovejoy 1997). Reasons for threat to marine life include human consumption, overexploitation, dumping of waste, pollution, land reclamation, dredging and global climate change (Beatley 1991; Irish and Norse 1996; Tickel 1997; Snelgrove 1999; Ramesha et al. 2011).

Anthropogenic marine debris originate from littering, manufacturing plants, intentional/accidental release from ships, offshore drilling platforms, landfills and storm drains. Deficiencies in the implementation/enforcement of international and regional environmental laws as well as the lack of infrastructure to mange solid waste combined with absence of awareness among stakeholders are major reasons for marine litter. As per UNEP (2005) more than 13,000 pieces/square kilometres are floating on ocean surface. Seas have been used for hundreds of years, as a place to dispose radioactive waste. Packaged LLW have been disposed at more than 50 sites in Atlantic and Pacific Oceans. First, a sea disposal was done in 1946. The last known sea disposal happened in 1982. Between 1946 and 1982 about 1.7 MCi of radioactive waste were disposed into sea packaged in typically in metal drums lined with concrete/bitumen matrix. Seafloor debris of 101,000 items/km^2 was recorded in European waters and 690,000 items/km^2 in Indonesia Michelle et al (NA) Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) of The United Nations estimated 80 % of marine debris comes from land based activities and the remainder from sea-based activities (Sheavly 2005).

Marine litter causes environmental, economic, health as well as aesthetic problems by damaging marine and coastal biological diversity. Marine litter is capable of transporting invasive species. Medical and sanitary waste can create health hazard and can injure people. Marine debris can move around, remain floating, get entangled on sea bed. As per an estimation by the USA Academy of Sciences in 1997, the marine litter worldwide is about 6.4 million t per year and as per other calculations nearly 8 million pieces/day of marine litter enter oceans and seas out of which nearly 5 million pieces are thrown or lost from ships (UNEP 2005).

Debris from sea-based sources include fishing gear, waste from shipping and recreational boats. Debris from land based activity includes almost everything that can be indentified in solid waste. Apart from being litter problem, marine debris pose threat to wildlife as many marine animals as well as seabirds are killed/ injured because they get entangled by marine debris or since they ingest it. Plastic bags, fishing gear, nets can damage propellers and rudders of boats/ships as well as block water intakes in recreational boats. Fishing nets left/lost in the sea referred as ghost nets can enmesh many marine fauna by restricting movement thereby causing laceration, starvation and suffocation. Further plastic pellets used for plastics manufacturing enter marine environment due to accidental spillages. Every year container ships lose more than 10,000 containers in sea usually during storms adding to the waste already entered from activities on land (Janice 2001).

As per Takashi and Noda (2003), the mean concentrations of litter along beaches studied in Russia and Japan were 1,344/100 and 2,144 g/100 m^2, respectively. The number of pieces of litter in Russia and Japan as per the studies were 20.7/100 and 341/100 m^2, respectively, with plastic being the most abundant among the type of stranded litter accounting 40–80 % of the waste. Further mean concentration of bur0ied litter in Russia and Japan was 2.70 and 9.03 g/m^2, respectively.

The debris and litter problem are not just restricted to a few countries. Studies in Ligurian Sea during 1997 suggest a debris density was between 15 and 25 objects/km^2 and during the year 2000. The debris density was between 3 and 1.5 objects/km^2 (Stefano et al. 2003) during 1996. Floating marine debris (FMD) comprising of 86.9 % plastic materials was reported by Thiel et al. (2003) in coastal waters off the Chilean coast during 2002 with highest densities in near waters of major port cities. Oceanic circulation patterns deposit considerable debris in Hawaiian Archipelago which has led to the formation of multiagency marine debris working group (Mary 2003).

Between 1960 and 2000, production of plastic resins worldwide increased by 25-fold, whereas recovery of plastic remained below 5 % (Charles 2008). Between 1970 and 2003 it became the fastest growing fraction of the US municipal waste stream, raising nine-fold there by making 60–80 % of marine litter plastic, reaching 90–95 % in some areas (Charles 2008). As per the studies made by Gerhard (2002), 80 % of floating plastic debris on a Dutch coast had peckmarks made by sea birds as these birds. Studies made by (Leandro et al. 2001) in Rio Grande do Sul State, Brazil on turtles revealed plastic bags in esophagus/stomach contents. Three juvenile Brazilian sharp nose sharks caught in southeast Brazil had plastic debris around gill or mouth had caused abrasion on the sharks' tissues (Ivan et al. 2002).

Versatility of plastic has led to an increase in their use and they have occupied in all aspects of life. Durability and non-degradability of plastics have become the threat to the environment. As they are buoyant it is dispersed over long distances. In 1975 about 135,400 t of fishing gear made up of plastic and 23,600 t of artificial packaging material was dumped into sea by fishing fleet (Cawthorn 1989; DOC 1990). It was also reported that about 639,000 plastic containers are dumped by merchant ships each day around the world (Horsman 1982). Recreational fishing and boats dispose about 52 % of all the solid waste discarded in the USA waters (UNESCO 1994). Plastic pellets are observed in non industrial places like Rarotonga, Tonga, and Fiji (Gregory 1999). In New Zealand beaches over 100,000 raw plastic granules/sq.m was reported of coast in as back as 1989 (Gregory 1989). Discarding of plastic debris in ocean is an increasing problem. Plastic debris in South African beaches increased in five years (Ryan and Moloney 1990) and 50 % of their original trash load was regained just after three months (Garrity and Levings 1993).

As per Laist (1997), the plastic debris affects minimum 267 species out of which 44 % of seabird species, 86 % sea turtle species, as well as 43 % of marine mammal species. Robards et al. (1995) observed increase in ingestion of plastics by seabirds during study period. As per Schrey and Vauk (1987) 13–29 % of the observed death of gannets occurs due to entanglement at Helgoland, German Bight.

12.3 Greenhouse Gas Generation and Climate Change

The international literature on the connection between climate change and waste is mainly focused on MSW and there is limited reference to the impact of other waste streams. The waste management sector is becoming a main contributor to reducing GHG emissions (UNEP 2010). The classification of waste varies from one country to other and makes it difficult to distinguish separate waste streams for international comparison.

All waste management components generate GHG which include, storage, collection, transfer, transportation and waste processing. Recycling reduces GHG emissions as it lowers the energy demand for production. The major GHG emissions in waste sector are landfill, incineration and open burning of waste. Data uncertainties are expected to be high in waste sector. GHG from waste sector accounts for less than 4 % of global GHG output with major fraction of emissions generated from landfill (Kevin et al. 2005; Chen and Lin 2008).

The generation of GHG and subsequent climate change can affect the life on earth and livelihood of millions (**Box 12.2**).

GHG emissions can be controlled by landfill CH_4 recovery, and controlled aerobic composting and incineration for waste-to-energy. Currently, landfill gas is being used to fuel boilers, to generate electricity, and to produce a substitute natural gas. Diverting biodegradable waste from landfills will benefit climate. Waste prevention, minimization, recovery, recycling and re-use will also add to reduction of GHG emissions by decline in waste production, lower raw material consumption, decline in energy demand and fossil fuel.

A secondary control on landfill methane emissions is by oxidation by aeration. Field studies have proved that oxidation rates can be more than 200 $g/m^2/d$ in thick, compost-amended 'biocovers' (Bogner et al. 2005; Huber-Humer 2004). Lignin is a refractory and the cellulosic fractions decompose slowly. Therefore at least 50 % of the organic carbon land filled will not be converted to biogas carbon. Landfill carbon storage makes land filling a better alternative from a climate change perspective (Micales and Skog 1997; Pingoud et al. 1996; Pipatti and Savolainen 1996; Pipatti and Wihersaari 1998).

Box 12.2 Consequences of climate change

The term climate change means noticeable change in the Earth's global or regional climate over a longer period of time. Climate change depends on the quantity of energy entering and leaving the Earth. Destabilizing influences that can alter earth's radiative equilibrium are called climate forcings. A forcing will trigger melting of snow/glaciers/polar ice.

After centuries of civilisation it is now confirmed that the GHGs generated can capable of destroying civilisation if not combated in time. Accumulation of GHG leads to absorption of energy entering earth's atmosphere leading to global warming.

Global warming will not be uniform through out the earth. As a consequence there will be variation in wind movement and raining patterns. The change in climate change the rhythm of seasons, change in flowering time in plant, affect ecological cycles, leads to hydro-meteorological disasters, and cases rise in sea level.

Variability in the sea surface temperature (SST) of the Bay of Biscay as well as adjacent regions during the period 1854–2010 was studied by Carlos and Robin (2010) and observed about 25 % of the interannual variability during the last 150 years. New alien species arrivals in Aegean Sea since 1929 is studied by Maria et al. (2011) and found that that alien introduction rate parallels the increase of marine temperatures.

Climate change can affect population of phytoplankton on which other sea species depend. The global warming can trigger rise in population of vectors like mosquitoes and can disrupt health of humans/animals.

The change in climate can affect agriculture due to absence of rain in sowing season and raining in harvest season. The agriculture will also get affected due to increase in pests.

The impact on biodiversity is well recorded. There will be change in demography of species thus affecting food chain.
The hydro-meteorological disasters like cyclone, storms, floods can trigger other disasters like land slides. Such series of disasters can affect regional and global economy which may ultimately leads to loss of livelihood and unemployment.

Results from landfill CH_4 emissions measurements show a range of about 0.1–1.0 t CH4/ha/d (Nozhevnikova et al. 1993; Oonk and Boom 1995; Borjesson 1996; Czepiel et al. 1996; Hovde et al. 1995; Mosher et al. 1999; Tregoures et al. 1999; Galle et al. 2001; Morris 2001). Worldwide CH_4 emissions from landfills is about 500–800 $MtCO_2$-eq/yr (US EPA(2006; Bogner and Matthews 2003). The execution of an active landfill gas withdrawal system with vertical wells or horizontal collectors is the most important mitigation method to reduce emissions (Bogner et al. 2007).

Incineration for energy production, production of refuse-derived fuel (RDF) and co-combustion in industry reduces the mass of waste and can reduce use of fossil-fuel. Incineration has been widely used in many countries which have limited space for land filling. Nearly 130 million t of waste are combusted annually worldwide more than 600 plants in 35 countries (Themelis 2003).

The growth in emissions from land fill has decreased during the past 20 years due to increase in landfill CH_4 recovery and decrease in land filling in the EU. The recovery and the use of landfill CH_4 was first commercialized in 1975 and is being implemented at more than 1,150 plants worldwide emission more than 105 $MtCO_2$-eq/yr (Willumsen H 2003; Bogner and Matthews 2003).

The ozone-depleting substances (ODS) can prevail for many years in waste and occur as minute quantities in landfill gas. Release of ODS from rigid foams during use are small (Kjeldsen and Jensen 2001; Kjeldsen and Scheutz 2003; Scheutz et al. 2003), hence most of the ODS is still present after the end of their useful life. Many of the ODS which are also GHGs like Carbon Tetrachloride (CTC) have been phased out during execution of Montreal protocol.

Many countries perform composting and anaerobic digestion of waste. CH_4 and N_2O can be formed during composting. Denmark, Germany, Belgium and France have installed anaerobic waste digestion systems with biogas recovery for heating, and onsite electrical generation.

GHG emissions in controlled biological treatment are minute when compared to uncontrolled GHG emissions from landfills without GHG recovery (e.g. Petersen et al. 1998; Hellebrand 1998; Vesterinen 1996; Beck-Friis 2001; Detzel et al. 2003). On the other hand WTE reduces GHG by an estimated one tonne of CO_2 per tonne of waste combusted rather than land filled. Burning of of MSW in WTE facilities of the USA reduces GHG emissions by about 26 million t of CO_2 (Psomopoulos et al. 2009).

Aerobic composting emits methane and nitrous oxide. The quantity of emission from compost varies depending on the waste and process. Closed systems, like enclosed maturation bays and housed windrows, emit lesser GHG emission. GHG emissions from anaerobic digestion are limited to fugitive emissions from leakages.

After waste prevention, recycling will result in the highest climate benefit (ISWA 2009, Christensen et al. 2009a, b; US EPA 2006b; Pimenteira et al. 2004; Chintan 2009). But still most of the consultants who take up solid waste management in third world under aegis of international funding agencies would often recommend landfills which were never operated in the countries and lack expertise in operating landfill. As a result with in short span the landfill would be source of many problems along with GHG emission.

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Chapter 13
Issues in Disaster Affected Area

Disasters can occur due to natural or anthropogenic activities. The disasters could be sudden onset (as in case of earthquake, fire, and flood, explosion in industry, and hurricane) or prolonged onset (such as civil conflict or drought). They are abrupt generally shocks which are non-routine events and would affect social, ecological and economic stability of the affected region. Disaster synonyms include “calamity”, “catastrophe”, “emergency” and “crisis”.

Disaster waste can impede rescuers as well as emergency services reaching survivors. It will pose a public health hazard and, delay the social and economic revival of the affected area. Improper clean-up effort can prove potentially risky to environment and public health (Charlotte et al. 2010).

Waste management has been cited as a main weakness in the recovery phase of natural disasters. Extraordinary investments by aid agencies in waste disposal and management during post disaster activities are usually not accompanied by awareness-raising campaigns on civic responsibility, hygiene and the benefits of waste recycling thereby leading to failure of the intention. The collection of disaster waste happens in two stages: (1) to clear debris those obstructs emergency areas and eliminate/mitigate the exposure to hazardous waste, (2) to clear the debris to facilitate reconstruction.

Evidence from disasters shows that the post disaster waste dumping in poorly planned landfills or wetlands has affected crop growth, fishing, ecosystem and public health. Factors that have contributed to poor waste management endeavour in prior post disaster initiatives are: (1) absence of formalized waste management system, (2) Non-integration of environmental standards into waste management, (3) clearing and processing of wastes are done on an ad-hoc manner, (4) over-burdened pre-existing facilities usually does not have access to the proper machinery required to demolish/manage large-scale debris, (5) little technical experience with most international humanitarian agencies (UNDP and ISDR NA).

Considering the experience of relief aid agencies over the years the principles to tackle disaster waste are: (1) avoid ad-hoc approach for disaster waste management,

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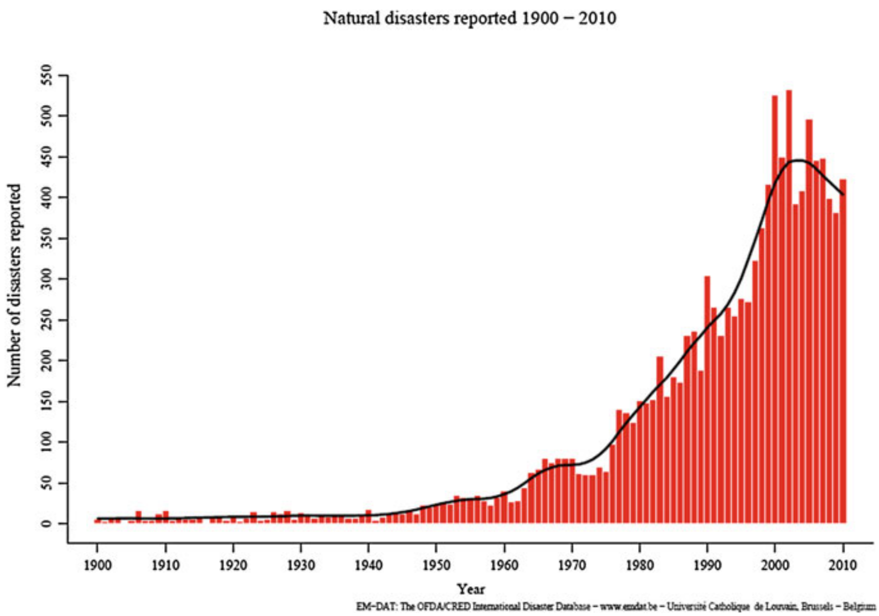

Fig. 13.1 Natural disasters reported worldwide from 1900 to 2010

(2) fix proper roles and responsibilities to waste handling agencies, (3) preselect waste disposal/storage locations, and (4) sort the waste at earlier stages.

It seems that 90 % of demolition waste can be recycled. Trees, vegetation and other biodegradable waste can be shredded/composted for use as manure, metals can be used for reconstruction/recycling. Wood can be used as fuel or rebuilding/repairing buildings, boats, platforms etc. Concrete and stone can be ground into aggregate for construction of roads/embankment/breakwaters.

More than 9,000 natural disasters have occurred since 1900 out of which about 80 % have occurred in last 40 years (Fig. 13.1). Every year more than 255 million people were affected due to natural disasters globally between 1994 and 2003, claiming an average of 58,000 lives per year (Guha-Sapir et al. 2004). Asia leads in terms of the disaster occurance and the number of people affected. Asian population represents nearly about one-third of the total landmass and three-fifths of the world population with population of India, Bangladesh and China, being affected the highest by natural disasters (Table 13.1).

In the last decade of the twentieth century disasters caused damage of nearly US $67 billion per year. The economic cost associated with natural disasters has risen 14-fold since the 1950s (Guha-Sapir et al. 2004).

The management of solid waste from natural and manmade disasters is unique in the fact that a reduction of the quantity of waste at its source is not possible. Reusing and recycling of waste need to be considered with the respect different types of wastes such as organic waste generated during preparing foods at camps. Food waste need to be collected as fast as possible and treated/disposed. In high

Table 13.1 Type of disaster and examples

Sl. no.	Type of disaster	Example
1	Natural	Avalanches, droughts, cyclones, earthquakes, dust/sand storms, epidemic diseases, floods, famines, heat waves, hurricanes, lightening storms, landslides/mudslides, tornadoes, typhoons, volcanic eruptions, wild fires
2	Anthropogenic	Environmental disasters, accidents (industrial, bio-terrorism, nuclear, radiological, transportation), fire, explosion, spreading chemical agents, dam failures, mass hysteria, assassinations, sabotage, vandalism

density camps, the wastes need to hauled away twice daily. Treatment options for organic waste include composting and anaerobic digestion. Plastic in the form of bottles, boxes, plastic bags may pileup if not re-used or disposed. Plastic together with paper may litter the camps and choke drains if not properly handled.

Disaster waste can be generated during the response and recovery phases after disaster. Public health can deteriorate due to spread of infection, toxicity and injury. The presence of disaster waste impacts can cause road blockages. Road blockages due to Great Hanshin-Awaji earthquake in Japan during 1995 prevented access to people involved post disaster operations (Kobayashi 1995). Similar situation reoccurred in the month of March 2011 when the Japan was affected by earth quake and Tsunami.

Hurricane storm surges can shift industrial wastes away from their source location thereby impacting on the wider community (USEPA 2008) tornado debris in the US was often twisted and hence difficult to separate as well as recycle (Reinhart and McCreanor 1999). It was observed during Haiti earth quake in 2010 that communities were not able to contribute to the clean-up effort due to the heaviness of the collapsed masonry structure (Booth 2010).

The management of disaster waste is more challenging than the waste generated during normal period. The main reasons are:

1. Waste management the least prioritized in the developing countries (compared to poverty alleviation, food, clothing and shelter) with no resource is left for planning and acting during disasters,
2. Waste management crew would have injured or expired during disaster,
3. Vehicles used for waste management would have damaged beyond repair,
4. The transportation network would have affected,
5. There would be confusion in the disaster struck area,
6. Organic matter and stagnant water can become vector breeding grounds during disaster,
7. Epidemic out break would demand high quality personal safety clothing and equipment,
8. Quantity of infectious waste and hazardous waste would have increased due to contamination, and.

9. Disposal sites would have also damaged making it difficult to find new site until the existing one is repaired (Table 13.2).

Depending on the nature and severity, disasters can create large quantities of debris and waste (Charlotte et al. 2011). The major contribution for the waste comes from collapsing of building. The building size varies depending on country to country. As per studies conducted in Japan by Hirayama et al. (2009, 2010) debris generated during disaster vary between 30 and 113 t/household.

Public health risks can increase during disaster due to: (1) contact with waste accumulated in disaster affected area, (2) vectors and rodents, and (3) post disaster collapse of unstable structures. Environmental impacts due to disaster waste include disturbance to eco system, change in species population, and loss of agricultural crops areas.

Apart from natural disaster invention and application of science has resulted in technological disasters. The trends in technological disaster over the last century are shown in Fig. 13.2. Both natural and technological disasters reached peak in the last decade and are showing downward trends (Table 13.3).

As per Reinhart and McCreanor (1999) debris volumes due to single disaster will be equivalent of 5–15 times the yearly waste generation rates by the affected community. Disaster waste during emergency response and recovery is affected by blocking the roads, creating fire, spreading diseases, causing injuries. The nature of disaster can change the original characteristics of waste due to contamination by chemical/pathogens. The weight of waste can be altered due to dampening during storm/rain/flood. One disaster can lead to other disasters. Natural disaster can lead to industrial accidents. Blocking of river/streams during earthquake/storm/avalanche can cause flooding.

Rapid deforestation has triggered disasters like floods and landslides in the past century killing people and destroying infrastructure, housing and harvests. Small but returning disasters can have a great impact on the development of nations. Recurrent floods in Bangladesh accounted a yearly loss of 5 % of the nations GDP (Guha-Sapir et al. 2004).

The first priority after a disaster or conflict will always be to meet the survival requirments of the affected population which includes the food, water, sanitation, shelter and medical care. But, the disaster waste quickly becomes a major concern, adding to problems. Disaster debris is often considered as the first sources of emergency energy and shelter as they provide fuel and building material.

Disasters generate large quantities of debris especially when the disasters take place in urban area. In the past, waste from disasters was buried or burned which is no more acceptable to many communities as citizens do not want to expose themselves to air pollutants and do not want to contaminate drinking water and soil. Waste if unattended will start decaying and contaminate surface/groundwater as well as emit flammable LFG. Conversely waste during disasters contains noteworthy quantities of recyclable/recoverable building materials which can be directly used for recovery operations.

Table 13.2 Quantity of waste generated in some of the disasters

Year	Disaster	Country	Quantity	Data source
2011	Earthquake and tsunami at Japan	Japan	80–200 million tonnes	
2010	Haiti earthquake	Haiti	23–60 million tonnes	Booth (2010)
2009	L'Aquila earthquake	Italy	1.5–3 million cubic metres of debris	Brown et al. (2010)
2008	Sichuan earthquake	China	20 million tonnes	Taylor (2008)
2005	Hurricane Katrina	USA	76 million cubic metres	Luther (2008)
2004	Hurricanes Frances and Jeanne, Florida,	USA	3 million cubic metres	Solid Waste Authority (2004)
2004	Typhoon Tokage	Japan	44,780 t	UNEP (2005)
2004	Indian Ocean tsunami	Thailand	0.8 million tonnes	Basnayake et al. (2006)
2004	Indian Ocean tsunami	Sri Lanka	0.5 million tonnes	Basnayake et al. (2006)
2004	Indian Ocean tsunami	Indonesia	10 million cubic metres	Bjerregaard (2009)
2004	Indian Ocean tsunami	Maldvies	290,000 m^3 of demolition waste, 50,000 m^3 of other waste	Shelter Centre et al. (NA)
2004	Hurricane Charley	USA	2 million cubic metres	MSW (2006)
2001	Terror attack on Twin Tower, Newyork	USA	1.6 million tons of debris	George Tchobanoglous(2002)
1999	Kosovo conflict	Kosovo	100,000 t	DANIDA (2004)
1999	Earthquake at Marmara	Turkey	13 million tonnes	Baycan (2004)
1998	Central Florida Tornadoes	USA	0.9 million cubic metres	Reinhart and McCreanor (1999)
1995	Great Hanshin-Awaji earthquake, Kobe,	Japan	15 million tonnes	Hirayama et al (2009)
1994	Northridge earthquake, California	USA	7 million cubic yards of disaster debris	USEPA (1995)
1994	Simi Valley earthquake, California	USA	75,000 t	SARA (1995)
1993	Southern California fire	USA	64,000 t	GOES (2005)
1992	Hurricane Andrew, Florida	USA	40 million tons of debris	George Tchobanoglous(2002)
1992	Metro-Dade County earthquake, Florida	USA	43 million cubic yards of disaster debris in Metro-Dade County alone	USEPA (1995)
1992	Hurricane Iniki, Kauai, Hawai	USA	3.8 million cubic meter of disaster debris	USEPA (1995)
1989	Hurricanw Hugo, Mecklenburg County	USA	1.5 million cubic meter of green waste	USEPA (1995)

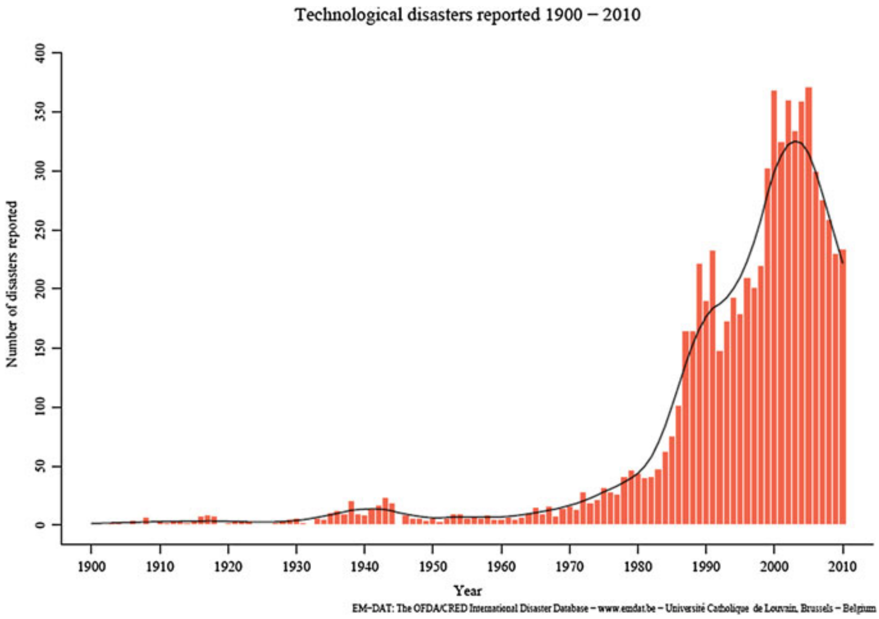

Fig. 13.2 Technological disasters reported worldwide from 1900 to 2010

Table 13.3 Types of waste generated during various disasters

	War and Conflict	Earthquake/ land slide/ Avalanche	Fire	Flood	Hurricane	Cyclone / Tornado	Tsunami	Volcanic erruption
Ash and Charred Wood	✓		✓					✓
Building Waste	✓	✓	✓	✓	✓	✓	✓	✓
Damaged household goods	✓	✓	✓	✓	✓	✓	✓	✓
Domestic Waste	✓	✓	✓	✓	✓	✓	✓	✓
Hazardous waste	✓	✓	✓		✓	✓	✓	✓
Industrial waste	✓	✓	✓	✓	✓	✓	✓	✓
Relief Waste		✓	✓	✓	✓	✓	✓	
Soil and Sediment				✓			✓	
Vegetation		✓			✓	✓	✓	
Biomedical Waste	✓	✓	✓	✓	✓	✓	✓	✓

Global climate change will increase the occurrence of extreme events, creating more floods and windstorms and associated waste. Population rise, urbanization and the inability of populations to escape from natural disasters and environmental emergencies would further pose the challenge of disaster waste management.

Fig. 13.3 Tsunami affected area

Urbanisation as it is requires huge quanitiy of refined natural resource like cement made up of mined limestone, metals form ores, wood from forest. One tone of urban debris would have consumed twenty to hundred times natural resources which include ore, fuel, mineral and wood. The resbuilding disaster affected urban area means further consumption of natural resources which contributes to pollution and emission of GHG. The hurricane Mitch's impact on Honduras had set back the nation's development by 20 years (Guha-Sapir et al. 2004). Hence the possible solution should be the maximum utilization of the waste by reuse and recycle.

13.1 Tsunami

Tsunamis occur due to earthquakes, submarine landslides and volcanic eruptions. There are three destructive factors that occur during tsunamis: inundation, wave impact on structures and erosion. Tsunami induced currents can lead to erosion of foundations as well as the collapse of bridges and seawalls. Drag forces and flotation can move houses and overturn railroad cars. Damage is also caused from floating debris and becomes dangerous projectiles that crash into structures, break power lines and initiate fires. Fires from damaged ships, ruptured coastal oil storage tanks as well as refineries can add to damage GOES (2005).

Over the last 110 years 57 tsunamis occurred resulting in the death of more than 0.26 million people and affecting more than 2.9 million people. Figure 13.3 shows tsunami affected area in Andaman and Nicobar island of India. Depending on nature and severity, disasters can create large quantities of debris and waste as identified by Srinivas and Nakagawa (2008) in post tsunami which struck Sri Lanka in 2004. Tsunamis can cause extensive damage to infrastructure and spread debris over large areas. Debris is usually mixed with soils and other loose objects such as leaves, litter, rags etc. which makes waste difficult to handle and segregate.

Debris volumes from a single event can be 5–15 times the annual waste generation rates of the affected community (Basnayake et al. 2006; Reinhart and McCreanor 1999). Earth quake and tsunami during 2011 resulted in the collapse of 18,000 houses, partial damage to about 140,000. Miyagi prefecture of Japan alone, about 146,000 cars was destroyed. The disaster was responsible for 500,000 tons of rotting seafood in disabled port refrigeration facilities.

Most tsunami waste in Indonesia was removed by government appointed contractors. The quantity of waste generated in Kota Banda Aceh, Indonesia was about 85,00,000 m^3 (UNDP and BRR NA). The waste collected was dumped in temporary tsunami waste dumpsites at paddy fields, fish ponds and land near residential areas. Tsunami Waste Recovery Facilities (TWRFs) located in Aceh Barat and Kota Banda Aceh were engaged in clearing residual tsunami waste, demolish damaged buildings as well as recover recyclable objects using rented heavy equipment. TWRFs hired labour under their cash for work programme.

13.2 Earthquake

About 130 million inhabitants are affected on average every year to earthquakes (UNDP 2004). The quakes will typically occur due to tectonic plate movement but other phenomena like reservoir-triggered seismicity (RTS) can also cause earthquake wherein earthquakes are triggered by the physical processes that go with the impoundment of large reservoirs.

As summarized in Table 13.4, over the last 110 years, a total of 1,190 earthquakes were reported (which included those occurred in the sea resulting in tsunami) resulting in the death of more than 2.5 million people and affecting more than 170 million people.

Earthquake in 1999 at Marmara Region, Turkey resulted in about 13 million tonnes of waste. Waste management undertaken by the local municipalities without clear authority as well as accountability resulted in confusion of responsibilities, duplication of efforts, inefficient resource management and poor coordination (UNDP and ISDR NA).

Most earthquakes occur along the boundaries of the tectonic plates. About 80 % of the world's major earthquakes occur along a belt encircling the Pacific Ocean and hence this belt often refereed as 'Ring of Fire'. Earthquakes can further result in slope instability resulting in landslides and soil liquefaction.

Figure 13.4 shows the number of occurences of earthquake disasters by country: 1974–2003. Earthquakes can create large quantities of that can obstruct rescuers and emergency service providers. Earthquake debris usually contains construction materials, personal properties and sediments. Normally earthquake debris is too heavy for individuals to handle themselves (Booth 2010).

The earthquake in Kobe of Japan in January 1995 destroyed more than 192,000 buildings along with roads and railways resulting in about 15,000,000 m^3 of waste. The major portion of the waste was used for land recovery in Osaka bay or

Table 13.4 Summarized table of major earthquakes sorted by continent from 1900 to 2011

Area	Event	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Earthquake (ground shaking)	75	21,074	1,694,137	12,129,699
	Average per event		281	22,588.5	161,729.3
	Tsunami	4	312	109,913	230,000
	Average per event		78	27,478.3	57,500
Americas	Earthquake (ground shaking)	255	438,866	3,212,6046	100,759,906
	Average per event		1,721	125,984.5	395,136.9
	Tsunami	6	380	752	900
	Average per event		63.3	125.3	150
Asia	Unspecified	2	78	14,726	-
	Average per event		39	7,363	-
	Earthquake (ground shaking)	607	155,8247	127,286,260	309,976,074
	Average per event		2567.1	209,697.3	510,669
	Tsunami	33	262,388	2,843,168	222,637,000
	Average per event		7,951.2	86,156.6	6,746,575.8
Europe	Earthquake (ground shaking)	153	275,897	5,486,046	61,866,336
	Average per event		1,803.2	35,856.5	404,355.1
	Tsunami	4	2,376	2	-
	Average per event		594	0.5	-
Oceania	Earthquake (ground shaking)	41	609	691,015	17,879,419
	Average per event		14.9	16,854	436,083.4
	Tsunami	10	2,793	20,843	159,500
	Average per event		279.3	2,084.3	15,950

Created on: 22 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster Database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

removed to landfill. This resulted in the use of valuable waste landfill space and affected city's solid waste management systems (Shelter centre et al. NA).

An earthquake off the coast of Japan having a magnitude of 9.0 on Richter scale On 11 March 2011 triggered a tsunami of up to 30 m high wave that moved up to 5 km inland, resulting in the most costly disaster worldwide. The total quantity of waste was approximated between 80 and 200 million tons.

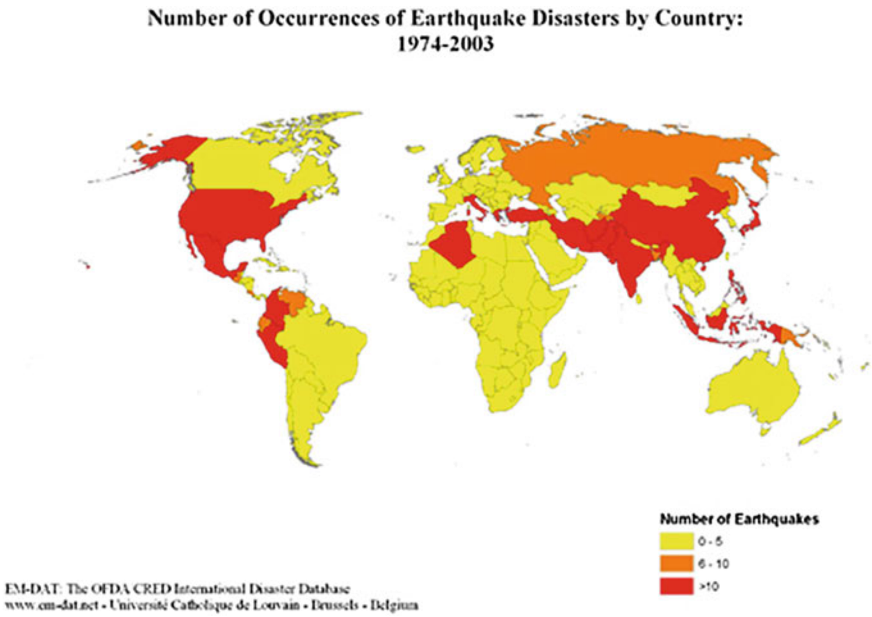

Fig. 13.4 Number of occurrences of earthquake disasters by country: 1974–2003

13.3 Haphazard Disposal of Hazardous Waste

Haphazard disposal of hazardous wastes can considered as technological disasters. 2,242 residents were displaced after dioxin was found in soil in Missouri, U.S.A in 1982. Release of Methyl Isocyanate gas in Bhopal resulted in severe disaster in India during 1984 (Banerjee 2001; E&DM 2003). 2,65,354 t of dioxin-contaminated material and soil from several sites in eastern Missouri was incinerated in 1996–1997 (E&DM 2003).

Haphazard waste disposal will not be usually be reported by industries or countries. The major reasons for haphazard disposal are the absence of infrastructure and legislation. Some developing countries pass legislation but do not create infra sturcture to dispose waste. In the absence of any expertise and experience governments look forward for entrepreneurs or funding agencies to take their responsibility by creating disposal facility and collecting waste.

In addition to intentional disposal of hazardous waste, other disasters can also create chemical spills due to damage of storage tanks. Plant shutdowns in a hurry during disasters can result in spills and damage to reactors and chemicals stored. Hurricanes Katrina and Rita were responsible for 166 reportable spill events (Ruckart et al. 2008).

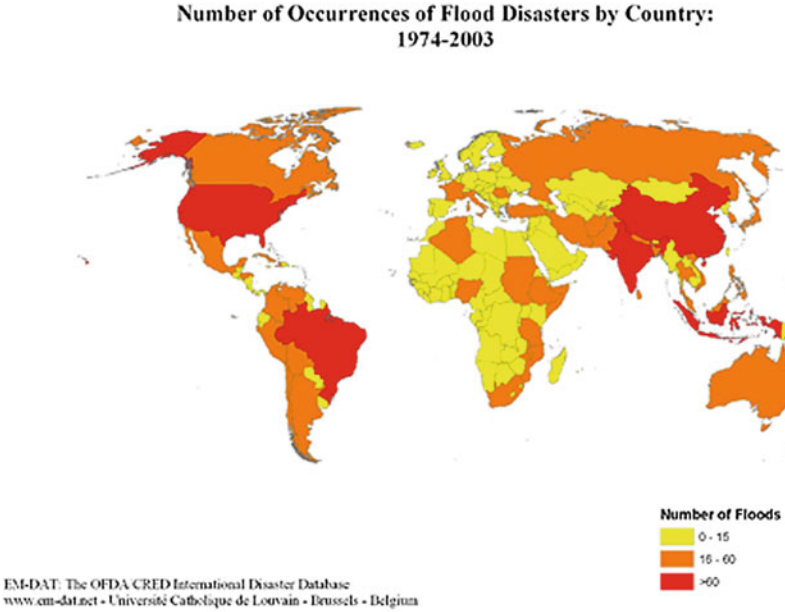

Fig. 13.5 Number of occurrences of flood disasters by country: 1974–2003

13.4 Flooding

About two-thirds of all natural disasters in the past three decades are of hydro-meteorological origins affecting the agricultural sector in rural areas. Figure 13.5 shows the number of occurrences of flood disasters by country between 1974–2003. The impacts include sweeping away harvests, destruction of plantations due to winds or rainfall, or floods. The Yangtze River floods in 1998 which occurred due to loss of forest in river basin in China killed more than 3,000 people and affected 230 million people (Guha-Sapir et al. 2004). Salado del Norte river flood of 2003 in Argentina resulted in dispersion of 60,000 tonnes of solid waste all over the city of Santa Fe (Bordón, 2003).

Floods (Figs. 13.6, 13.7, 13.8, 13.9) usually lead to mass displacement and require shelters and camps. This type of disaster leads to large volumes wastes, which is some time contaminated with hazardous substance making all the waste hazardous. Mould may be present and degradable material like food/timber/corpse may have begun to rot. Waste is usually mixed with soils and other loose objects such as leaves, litter, rags etc. makes waste difficult to handle and segregate. Flooding may bring soil and debris into affected areas, making access difficult even after the floodwater recedes. Soil in flooded area becomes soft and slurry there by making movement of people/vehicle difficult.

Fig. 13.6 Flood in semi urban area

Fig. 13.7 Flood in urban area

Fig. 13.8 Business in a street of flood affected area

Fig. 13.9 Dead animal after flood

Unlike in earthquake wherein waste will lie at same place, flood will carry the solid waste along with water flow. The dead animals and people will increase the chances of spreading disease worsening water and sanitation problems in the area. Choking of drainage system in the urban area would worsen the situation. It is highly impossible to collect the waste during flood and also waste collection will never be its first priority. The flood would carry floatable matter far away while the sinkable heavy objects would be dragged along the land on which the water flows.

The effect of flood on waste management depends on the extent of flood. Due to rapid urbanisation, settlements in developing world occur before storm water drains are built. Further the encroachments, street vendors, improper parking would result in impoundment even during small intensity of rain. Flood would increase the density of waste on the ground due to absorption of water by waste.

As summarized in Table 13.5, over the last 110 years, a total of 3,924 floods were reported resulting in the death of more than 6.9 million people and affecting more than 3,361.5 million people.

Improper drainage would also result in impoundment of water in low lying area along with waste it has picked. Flood would increase breeding of mosquitoes and other vectors. The infiltration of contaminants into groundwater in such situation cannot be ruled out. As soon as flood recedes, people begin to discard of flood-damaged items. Materials from demolished and dismantled houses also add to debris. After the Midwest flood during 1993, officials in Lincoln County, Missouri, managed the flood debris through drop-off centres and county collection. To comply with the solid waste regulations and recycling goals, staff of the county and contractors segregated the debris. The state of Missouri set aside its recycling policy temporarily, which prohibited land filling of compostable materials. A hazardous waste contractor disposed of household hazardous waste (USEPA 1995).

Large woody debris (LWD) affects the flow in the stream by accumulating in the stream along with other debris thereby causing morphological changes to stream. Debris clearing and restoration of stream is therefore necessary to avoid further damage due to erosion and increase in flood.

Table 13.5 Summarized table of floods sorted by continent from 1900 to 2011

Area	Events	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	221	6,909	13,592,362	965,007
	Average per event		31.3	61,503.9	4,366.5
	Flash flood	84	2,766	2,236,544	486,086
	Average per event		32.9	26,625.5	5,786.7
	General flood	464	13,893	38,112,116	4,740,184
	Average per event		29.9	82,138.2	10,215.9
	Storm surge/coastal flood	7	169	1,202,829	42,750
	Average per event		24.1	171,832.7	6,107.1
Americas	Unspecified	357	56,972	28,883,356	22,187,497
	Average per event		159.6	80,905.8	62,149.9
	Flash flood	62	32,398	2,758,310	4,839,870
	Average per event		522.5	44,488.9	78,062.4
	General Flood	485	12,715	50,264,807	55,349,840
	Average per event		26.2	103,638.8	114,123.4
	General flood/Mudslide	1	11	9,950	-
	Average per event		11	9,950	-
	Storm surge/coastal flood	17	1,070	1,054,818	1,212,720
	Average per event		62.9	62,048.1	71,336.5
Asia	Unspecified	529	2,365,297	863,319,573	41,796,252
	Average per event		4,471.3	1,631,984.1	79,009.9
	Flash flood	263	26,317	164,162,679	26,304,738
	Average per event		100.1	624,192.7	100,018
	General flood	780	4,396,231	2,163,138,598	209,538,462
	Average per event		5,636.2	2,773,254.6	268,639.1
	Storm surge/coastal flood	40	2,060	18,174,201	8,472,384
	Average per event		51.5	454,355	211,809.6
Europe	Unspecified	133	3,289	4,265,569	24,260,105
	Average per event		24.7	32,071.9	182,406.8
	Flash flood	45	1,629	535,689	14,471,710
	Average per event		36.2	11,904.2	321,593.6
	General flood	307	1,894	8,345,372	66,018,212
	Average per event		6.2	27,183.6	215,043
	Storm surge/coastal flood	7	2,028	615,531	342,622
	Average per event		289.7	87,933	48,946
Oceania	Unspecified	46	219	432,393	580,021
	Average per event		4.8	9,399.8	12,609.2
	Flash flood	18	90	36,939	1,892,100
	Average per event		5	2,052.2	105,116.7
	General flood	48	142	373,093	8,878,754
	Average per event		3	7,772.8	184,974
	Storm surge/coastal flood	10	14	78,030	252,500
	Average per event		1.4	7,803	25,250

Created on: 24 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster Database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

13.5 Hurricanes, Typhoons, Cyclones, Tornados

Hurricane is a large-scale closed counter-clockwise circulation system in the northern hemisphere and clockwise circulation system in the southern hemisphere in the atmosphere above the western Atlantic. They are charecterisised by strong winds and low barometric pressure with speed of 64 knots or more. Hurricanes are extremely disastrous and would carry waste along with revolving winds. As an end result there would be destruction along the pathway of the hurricane.

Cyclone (sometimes referred as tropical cyclones) is a large-scale closed circulation system in the atmosphere above the Indian Ocean and South Pacific characterized by low barometric pressure and strong rain, and winds of 64 knots or more. Cyclones form and intensify above warm water of the ocean surface due to warming of the atmosphere. Typhoon is large-scale closed circulation system in the atmosphere above the western pacific with maximum wind speed of 64 knots or more.

Strong winds of hurricanes, typhoons and cyclones are likely to shear and tear the roof off buildings followed by collapse of walls. Poorly constructed buildings can fold under roof too. Waste will be spread in open land, streets, playgrounds and marketplaces over large areas. Ships and boats are thrown aground and destroyed. Ships will sink in harbours.

Hurricanes produce high-velocity winds, make oceans to surge above high tide levels, and generate waves in inland waters. Hurricanes will result in debris made up of damaged buildings, construction materials, sediments, and green waste. Hurricane debris obstructs roads and disables communication systems as well as electrical power over wide areas. The majority of the damage and debris generation will occur in the area where the hurricane first hits land and can extend many kms inland.

A tornado is a violently rotating column of air that is in contact with earth and cloud. Tornado may move with a velocity from 60 kmph to more than 450 kmph. They will have Narrow path of impact with length of impact stretching up to several km. The high winds of a tornado can throw vehicles several meters away, debark trees and severely damage structures. Table 13.6 gives a summary of storms sorted by continent from 1900 to 2011. Waste generated by Hurricane Katrina, costed over USD 3.2 billion to clean up.

In 1989, hurricane Hugo resulted in landfall at Charleston, South Carolina, and continued inland, causing damage in the state and North Carolina. The hurricane produced 400,000 tons of green waste in Mecklenburg County, North Carolina, 322 km (200 miles) from Charleston. All the debris was ground up into mulch and given to local citizens and businesses for use (USEPA 1995). The Caribbean island of Montserrat was distressed by Hurricane Hugo, with nearly 98 % of the houses being damaged or destroyed (Guha-Sapir et al. 2004).

Secondary impacts due to hurricanes/typhoons/cyclones/tornados include flooding, mudslides, building collapses, erosion, downed and falling of trees.

Table 13.6 Summarized table of storms sorted by continent from 1900 to 2011

		Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	54	581	95,480	3,725
	Average per event		10.8	1,768.1	69
	Local storm	52	1,053	399,044	668,563
	Average per event		20.3	7,673.9	12,857
	Tropical cyclone	101	3,516	15,091,328	3,079,430
	Average per event		34.8	149,419.1	30,489.4
Americas	Unspecified	256	9,070	2,862,976	34,197,240
	Average per event		35.4	11,183.5	133,583
	Extratropical cyclone (winter storm)	2	15	1,600	1,000,000
	Average per event		7.5	800	500,000
	Local storm	288	7,810	1,093,349	85,192,160
	Average per event		27.1	3,796.4	295,806.1
	Tropical cyclone	572	86,378	48,017,886	416,430,732
	Average per event		151	83,947.4	728,025.8
Asia	Unspecified	270	15,382	52,376,141	4,703,956
	Average per event		57	193,985.7	17,422.1
	Local storm	172	6,728	187,047,261	7,889,889
	Average per event		39.1	1,087,484.1	45,871.4
	Tropical cyclone	970	1,238,258	571,894,381	155,039,873
	Average per event		1,276.6	589,581.8	159,834.9
Europe	Unspecified	203	5,338	4,108,848	32,201,800
	Average per event		26.3	20,240.6	158,629.6
	Extratropical cyclone	48	241	3,404,605	31,026,989
	Average per event		5	70,929.3	646,395.6
	Extratropical cyclone (winter storm)	28	165	503,772	18,457,150
	Average per event		5.9	17,991.9	659,183.9
	Local storm	116	1,380	612,754	9,986,546
	Average per event		11.9	5,282.4	86,090.9
	Tropical cyclone	22	201	94,682	1,817,360
	Average per event		9.1	4,303.7	82,607.3
Oceania	Unspecified	46	59	3,538,285	1,172,672
	Average per event		1.3	76,919.2	25,492.9
	Local storm	33	287	426,114	6,132,728
	Average per event		8.7	12,912.5	185,840.2
	Tropical cyclone	199	1,721	2,301,553	7,464,364
	Average per event		8.6	11,565.6	37,509.4

Created on: 27 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

13.6 War and Conflict

Conflicts can involve explosives like rockets, missiles and bombs damaging infrastructure/vehicles/housing. Damaged infrastructure is often burnt with most internal furnishings and fittings. This results in non-combustible material such as metal, concrete, bricks and stones. Bridges, roadways, railway structures etc. are often would have destroyed/damaged making the transportation of waste a difficult task. Waste collection vehicles would have damaged or might be used for armed forces. Unexploded ordnance may be present in waste and undetonated landmines may impede waste handling. Trace elements of chemical used during conflict may still be present in waste. Lethality of the chemicals employed varies from chemical to chemical (30 min for tabun to 2 years for mustard gas). Literature on waste quantity and quality due to war and conflict is not easily availble. However it seems that more than 290 metric tons of depleted uranium projectiles were fired into Iraq, more than 600 oil wells were exploded producing up to 500,000 metric tonnes of pollutants per day, and 25–50 million barrels released on land and sea during the 1991 Gulf War (Hassan 2008) resulting in a large quantity of waste.

Solid waste generated during civil unrest and terrorist act will have similar characteristics but usually occur for different reasons. The civil unrests will generate solid waste that includes burning structures/cars, broken glass, and destroyed buildings. Civil unrests are usually spontaneous, can quickly get out of hand. It will start at one location and spreads out. Emergency responders often become targets during civil unrest. Terrorist act will involve explosions, fire and chemical/biological attack. Terrorism will occur with little or no warning and usually targets airports, bus stand, railway station, government offices, popular landmarks, utilities, nuclear plants etc. (GOES 2005).

Studies suggest that about 40 % of total corruption in global transactions (Andrew et al. 2011) occur in arms trade. Such practice would only increase waste. The 10 largest military spenders during 2010 accounted for 75 % of world military spending with accounting for 43 per cent, and China in second place (Sam 2011).

As on September 2010, out of the world's declared stockpile of 71,194 t only 44,131 t of chemical agent is verifiably destroyed (OPCW NA; Mike 2011). 300,000–400,000 abandoned chemical weapons are remaining in China from Second World War (Mike 2011). After the Second World War Britain had more than two million tons of phosphorus flares, mortars, munitions–artillery shells, incendiaries and cluster bombs which were dumped at Beaufort Dyke, a 30 mile trench between Scotland and Ireland. Dumping also included 14,000 t of phosgene-filled rockets. Phosgene, a colourless poison gas can cause severe lung damage (PPU NA).

Table 13.7 Summarized table of wild fires sorted by continent from 1900 to 2011

Area	Events	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	1	49	3,023	-
	Average per event		49	3,023	-
	Bush/Brush fire	3	42	2,920	430,000
	Average per event		14	973.3	143,333.3
	Forest fire	9	66	11,140	-
	Average per event		7.3	1,237.8	-
	Scrub/grassland fire	13	117	14,532	10,000
	Average per event		9	1,117.8	769.2
Americas	Unspecified	4	1	56,823	2,016,000
	Average per event		0.3	14,205.8	504,000
	Forest fire	95	1,410	464,455	16,301,800
	Average per event		14.8	4,889	171,597.9
	Scrub/grassland fire	22	106	706,993	3,067,100
	Average per event		4.8	32,136	139,413.6
Asia	Forest fire	50	734	3,266,839	11,903,500
	Average per event		14.7	65,336.8	238,070
	Scrub/grassland fire	32	22	9,006	-
	Average per event		0.7	281.4	-
Europe	Unspecified	2	82	-	-
	Average per event		41	-	-
	Bush/Brush fire	1	53	5,996	1,800,000
	Average per event		53	5,996	1,800,000
	Forest fire	89	420	1,288,200	10,343,811
	Average per event		4.7	14,474.2	116,222.6
	Scrub/grassland fire	4	14	800	675,000
	Average per event		3.5	200	168,750
Oceania	Unspecified	1	-	-	-
	Average per event		-	-	-
	Bush/Brush fire	1	180	9,954	1,300,000
	Average per event		180	9,954	1,300,000
	Forest fire	5	24	4,011	468,650
	Average per event		4.8	802.2	93,730
	Scrub/grassland fire	25	292	83,175	854,194
	Average per event		11.7	3,327	34,167.8

Created on: 23 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

Fig. 13.10 Wild fire

Fig. 13.11 Destruction after a wild fire

13.7 Wild Fires

Wild fire is an uncontrolled fire in wildlands resulting in huge damage, health problems, and deaths to humans and other species. Fire could be caused due to anthropogenic or natural causes. Every year fires burn nearly 500 million hectares of open forests, woodland, tropical and sub-tropical savannahs, 20–40 million hectares of tropical forests, and 10–15 million hectares of boreal and temperate forest (Goldammer 1995). Forest fires will surge due to climate change. The strength and occurrence of El Niño could be escalating due to climate change (Trenberth and Hoar 1996, 1997), and may result in more forest fires.

As summarized in Table 13.7, over the last 110 years, a total of 357 major wild fires were reported affecting more than 5.9 million people.

Figure 13.10 shows a wild fire and Fig. 13.11 shows the destruction after the wild fire. Anthropogenic reasons for forest fire include shooting by poachers, cooking in forests, sparks from equipment, preparation of forest land for agriculture by intentional firing, discarded cigarettes and power line arcs. In many places fire is a tool for changing forests to agricultural lands (Stolle et al. 2003). The main natural reasons of wildfire are spontaneous combustion, volcanic eruption, lightning, sparks from coal seam fires and rock falls.

The fires of 1997/1998 in Indonesia were because of fires lit to clear and prepare land and accidental fires in forest and peat swamps (Daniel and Louis 2007). The July heat wave in 2010 resulted in intense fires across the Russia. Extended periods of minimal rainfall was the reason for forest fire in Southeast Asia during Ice Age (ADB 2001).

The forest fires of 1997/1998 produced massive ecological damage and human suffering. The fires destructed South-east Asia—from Papua New Guinea to Malaysia with fires in Borneo, Sulawesi, Irian Jaya, Java, and Sumatra, but Indonesia burned the most. Moscow was covered with dark smog in August 2010 because of peat fires raging around the city.

Even though wastes are relatively low compared to other disasters, demolished houses contribute non-combustible debris. De-vegetated slopes are vulnerable to mud-slides/landslides leading to generation of additional waste. The smoke can hinder the established solid waste management system due to low visibility as well as sickness of solid waste management personnel. Burned out cars, ash, and charred wood wastes also become part of waste during wild fire. In Malibu, California coastal fires destroyed 268 houses. The city chipped some trees for mulch and left other dead trees to help prevent erosion after which it gave property owners six weeks to eliminate their own debris, and then began removing rest of household debris. During wild fire, the quantity of solid waste the city collected as much quantity of solid waste it would usually collected in an entire year (USEPA 1995).

The 7 February 2009 bushfires in Victoria, Australia fuelled by severe drought conditions affected more than 430,000 ha of land (VBRRA 2009). The bush fire affected rural lifestyle, semiurban, farm, timber mills and forests, service towns, roads, power, fuel supply as well as telecommunications.

13.8 Industrial Accidents

Industrial accidents are generally localized and waste types depend on chemical released during the disaster. The quantum of the waste depends on size and type of industry. Fire accident in the industry (Figs. 13.12, 13.13, 13.14, 13.15, 13.16) with combustible materials like textile will generate less waste compared to car manufacturing facility. The industrial accident in chemical industry may generate waste across the city due to spread of poisonous gas killing humans and animals throughout the city. The industrial toxic fumes may also corrode metals around the industry and contaminate food and non food items making it a waste.

Fig. 13.12 Quenching after an industrial fire

Fig. 13.13 Spillage during a fire accident

Fig. 13.14 A day after a fire accident in a chemical industry

Fig. 13.15 Partially damaged structure during a fire accident

Fig. 13.16 Partially damaged raw material in a chemical industry during a fire accident

Table 13.8 Summarized table of industrial accidents sorted by continents during 1900 to 2011

Area	Events	No of events	Killed	Total affected	Damage (000 US$)
Africa	Chemical spill	4	105	1,430	-
	Average per event		26.3	357.5	-
	Collapse	37	1,285	183	-
	Average per event		34.7	4.9	-
	Explosion	44	3,677	8,180	896,400
	Average per event		83.6	185.9	20,372.7
	Fire	13	407	549	12,100
	Average per event		31.3	42.2	930.8
	Other	11	455	96,708	-
	Average per event		41.4	8,791.6	-
	Poisoning	6	425	22,423	-
	Average per event		70.8	3,737.2	-
Americas	Chemical spill	48	80	357,494	15,000
	Average per event		1.7	7,447.8	312.5
	Collapse	9	306	30	-
	Average per event		34	3.3	-
	Explosion	76	6,473	809,421	3,179,200
	Average per event		85.2	10,650.3	41,831.6
	Fire	27	309	95,289	123,500
	Average per event		11.4	3,529.2	4,574.1
	Gas leak	11	36	29,128	-
	Average per event		3.3	2,648	-
	Other	12	275	114	-
	Average per event		22.9	9.5	-
	Poisoning	9	157	552,950	-
	Average per event		17.4	61,438.9	-
	Radiation	2	17	200,488	-
	Average per event		8.5	100,244	-
Asia	Chemical Spill	18	14	125,938	57,554
	Average per event		0.8	6,996.6	3,197.4
	Collapse	53	1,809	565	15,000
	Average per event		34.1	10.7	283
	Explosion	448	16,462	172,829	583,874
	Average per event		36.7	385.8	1,303.3
	Fire	99	2,469	133,145	747,905
	Average per event		24.9	1,344.9	7,554.6
	Gas leak	27	2,707	458,806	-
	Average per event		100.3	16,992.8	-
	Oil spill	2	-	17,000	-
	Average per event		-	8,500	-
	Other	64	3,342	13,817	-
	Average per event		52.2	215.9	-
	Poisoning	48	2,527	50,950	-
	Average per event		52.6	1,061.5	-
	Radiation	4	28	327,729	-

(continued)

Table 13.8 (continued)

Area	Events	No of events	Killed	Total affected	Damage (000 US$)
	Average per event		7	81,932.3	-
Europe	Chemical spill	34	387	84,470	11,013,807
	Average per event		11.4	2,484.4	323,935.5
	Collapse	8	191	61	1,320,000
	Average per event		23.9	7.6	165,000
	Explosion	113	6,838	222,407	227,200
	Average per event		60.5	1,968.2	2,010.6
	Fire	35	684	17,094	1,724,500
	Average per event		19.5	488.4	49,271.4
	Gas leak	9	42	916	-
	Average per event		4.7	101.8	-
	Other	2	360	-	-
	Average per event		180	-	-
	Poisoning	10	404	22,199	-
	Average per event		40.4	2,219.9	-
	Radiation	3	41	535,935	2,800,000
	Average per event		13.7	178,645	933,333.3
Oceania	Chemical spill	1	-	1,500	-
	Average per event		-	1,500	-
	Explosion	4	51	2,062	12,000
	Average per event		12.8	515.5	3,000
	Gas leak	1	-	12,643	-
	Average per event		-	12,643	-

Created on: 27 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

As summarized in Table 13.8, over the last 110 years, a total of 1,292 industrial accidents were reported resulting affecting more than 4.4 million people. Table 13.9 gives a summarized table of miscellaneaous accident sorted by continent from 1900 to 2011. Table 13.10 gives a summary of transportation accident sorted by continent from 1900 to 2011.

13.9 Landslide

A landslide is the downward and outward movement of soil/rock material on slopes and is triggered due to rock falls, deep failure of slopes and shallow debris flow. Landslides can occur due to natural and artificial causes. One or more of the following condition lead to land slide: (1) fine-grained permeable rock or sediment, (2) clay or shale layers subject to lubrication, (3) jointed rocks, (4) steep slope, and (5) large quantity of water.

Table 13.9 Summarized table of miscellaneaous accidents sorted by continents during 1900 to 2011

Area	Events	Number of events	Killed	Total affected	Damage (000 US$)
Africa	Collapse	46	1,109	6,828	-
	Average per event		24.1	148.4	-
	Explosion	28	1,753	49,135	-
	Average per event		62.6	1,754.8	-
	Fire	85	1,105	280,853	35,950
	Average per event		13	3,304.2	422.9
	Other	39	1,256	87,073	4,000
	Average per event		32.2	2,232.6	102.6
Americas	Collapse	47	3,154	5,715	-
	Average per event		67.1	121.6	-
	Explosion	18	876	5,404	87,100
	Average per event		48.7	300.2	4,838.9
	Fire	135	9,863	78,447	80,558
	Average per event		73.1	581.1	596.7
	Other	34	1,217	1,746,424	-
	Average per event		35.8	51,365.4	-
Asia	Collapse	122	6,140	270,513	245,000
	Average per event		50.3	2,217.3	2,008.2
	Explosion	91	2,219	22,296	26,000
	Average per event		24.4	245	285.7
	Fire	296	18,482	751,553	931,911
	Average per event		62.4	2,539	3,148.3
	Other	94	6,807	29,560	-
	Average per event		72.4	314.5	-
Europe	Collapse	28	2,272	9,681	38,800
	Average per event		81.1	345.8	1,385.7
	Explosion	32	819	19,133	256,000
	Average per event		25.6	597.9	8,000
	Fire	94	2,769	6,241	705,000
	Average per event		29.5	66.4	7,500
	Other	33	696	4,322	-
	Average per event		21.1	131	-
Oceania	Collapse	2	14	12,004	-
	Average per event		7	6,002	-
	Fire	8	76	1,341	3,300
	Average per event		9.5	167.6	412.5
	Other	1	25	-	-
	Average per event		25	-	-

Created on: 27 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

Mountain region is affected by avalanches and landslides. Landslides bring debris with them. The quantity of waste is proportion to magnitude of landslide

Table 13.10 Summarized table of transportation accidents sorted by continents during 1900 to 2011

Area	Event	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	1	16	-	-
	Average per event		16	-	-
	Air	142	7,043	1,377	42,800
	Average per event		49.6	9.7	301.4
	Rail	87	4,660	8,720	-
	Average per event		53.6	100.2	-
	Road	830	19,190	14,208	-
	Average per event		23.1	17.1	-
	Water	333	20,810	56,042	-
	Average per event		62.5	168.3	-
Americas	Unspecified	2	22	21	-
	Average per event		11	10.5	-
	Air	285	11,214	2,444	62,000
	Average per event		39.3	8.6	217.5
	Rail	80	3,064	11,914	-
	Average per event		38.3	148.9	-
	Road	342	8,141	6,228	-
	Average per event		23.8	18.2	-
	Water	132	12,848	18,394	23,000
	Average per event		97.3	139.3	174.2
Asia	Unspecified	1	13	32	-
	Average per event		13	32	-
	Air	260	14,994	1,907	39,300
	Average per event		57.7	7.3	151.2
	Rail	251	11,461	65,512	408,000
	Average per event		45.7	261	1,625.5
	Road	861	23,559	15,780	-
	Average per event		27.4	18.3	-
	Water	549	47,023	7,387	2,400
	Average per event		85.7	13.5	4.4
Europe	Air	247	11,909	2,295	-
	Average per event		48.2	9.3	-
	Rail	136	6,825	10,522	-
	Average per event		50.2	77.4	-
	Road	117	2,294	2,938	7,700
	Average per event		19.6	25.1	65.8
	Water	105	7,853	3,455	-
	Average per event		74.8	32.9	-
Oceania	Air	20	778	64	-
	Average per event		38.9	3.2	-
	Rail	5	257	285	-
	Average per event		51.4	57	-
	Road	4	83	39	-
	Average per event		20.8	9.8	-
	Water	9	437	155	-
	Average per event		48.6	17.2	-

Created on: 27 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

Table 13.11 Summarized table of dry mass movement sorted by continents during 1900 to 2011

		Number of events	Killed	Total affected	Damage (000 US $)
Africa	Landslide	2	59	200	–
	Average per event		29.5	100	-
	Rockfall	2	129	697	-
	Average per event		64.5	348.5	-
	Subsidence	1	34	300	-
	Average per event		34	300	-
Americas	Avalanche	3	144	44	-
	Average per event		48	14.7	-
	Debris flow	1	10	-	-
	Average per event		10	-	-
	Landslide	10	2,290	8,945	200,000
	Average per event		229	894.5	20,000
	Rockfall	4	277	41	-
	Average per event		69.3	10.3	-
Asia	Avalanche	4	423	1,069	-
	Average per event		105.8	267.3	-
	Landslide	14	1,184	6,574	1,000
	Average per event		84.6	469.6	71.4
	Rockfall	1	50	-	-
	Average per event		50	-	-
Europe	Avalanche	6	167	1,802	2,600
	Average per event		27.8	300.3	433.3
	Landslide	3	102	8,506	-
	Average per event		34	2,835.3	-
Oceania	Unspecified	1	10	-	-
	Average per event		10	-	-
	Landslide	1	76	1,000	-
	Average per event		76	1,000	-

Created on: 23 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
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and development at the site. Landslide at undeveloped site would not generate waste as the soil, rock and vegetation would rearrange to form new landscape.

Table 13.11 gives summarized Table of dry mass movement sorted by Continent from 1900 to 2011 and Fig. 13.17 shows number of occurances of avalanche/landslide disaster by country between 1977 and 2003. Landslides can block valleys and stream channels resulting in water stagnate leading to upstream flooding. Failure of the blocked material leads to downstream flooding. Slope saturation by water is one of main cause of landslides. Climate change resulting in severe rainfall, snowmelt and flooding could favor landslides.

The quantities and characteristics of waste depend on the extent of the development and landslide. The land slide will also affect transportation of waste and associated flood can increase density due to absorption of water.

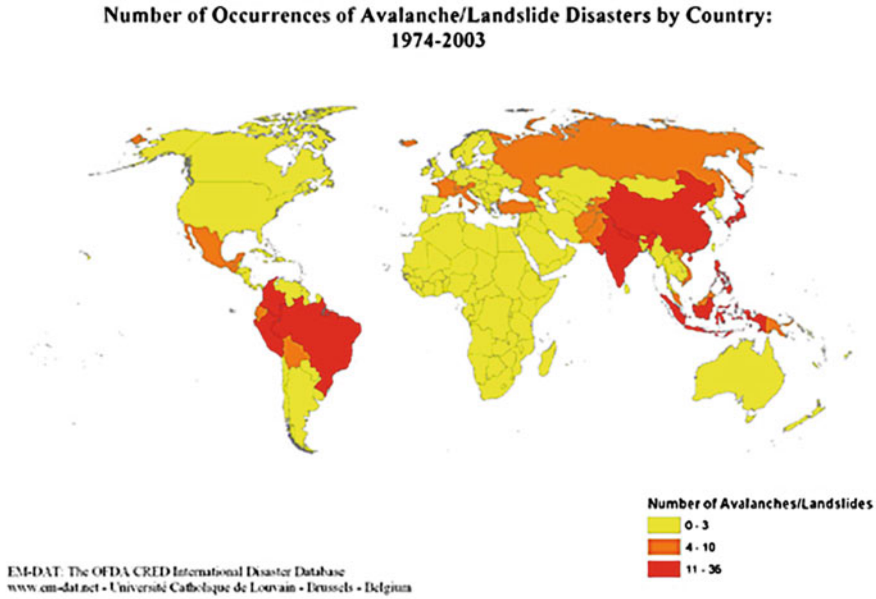

Fig. 13.17 Number of occurances of avalanche/landslide disasters by country during 1977–2003

13.10 Avalanche

Like landslide avalanche would generate waste proportionate to the magnitude of a disaster and development. Avalanche is the sudden flow of snow down a slope. It could occur due to natural triggers (like load of new snow/rain) or artificial triggers (like explosion, dumping waste). Avalanche can destroy rail, road, settlement, forest etc.

Table 13.12 shows summarized Table of wet mass movement sorted by Continent from 1900 to 2011. Avalanche would transfer debris, wood and structures on its way. The waste is usually visible after snow melts.

13.11 Drought

Drought would often generate less waste than any other disaster. People who are affected by drought often utilise as much resource as possible leaving behind little waste. The food is consumed completely and money is spent prudently. There would be less luxury and lavishness in the drought prone area. The disaster would also witness people moving out of the disaster prone area in search of livelihood.

Table 13.13 gives summarized table of drought sorted by continent from 1900 to 2011 and Fig. 13.18 shows number of occurrences of drought/famine disasters

Table 13.12 Summarized table of wet mass movement sorted by continents during 1900–2011

Area	Event	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Landslide	30	1,179	54,692	-
	Average per event		39.3	1,823.1	-
Americas	Avalanche	4	95	154	-
	Average per event		23.8	38.5	-
	Landslide	152	19,271	5,509,100	2,521,727
	Average per event		126.8	36,244.1	16,590.3
	Rockfall	1	33	-	-
	Average per event		33	-	-
Asia	Avalanche	44	2,476	57,827	50,000
	Average per event		56.3	1,314.3	1,136.4
	Debris flow	1	106	-	-
	Average per event		106	-	-
	Landslide	271	18,776	8,009,795	2,766,916
	Average per event		69.3	29,556.4	10,210
	Subsidence	1	287	2,838	-
	Average per event		287	2,838	-
Europe	Avalanche	33	1,201	13,119	774,889
	Average per event		36.4	397.5	23,481.5
	Landslide	34	15,339	25,378	2,334,000
	Average per event		451.1	746.4	68,647.1
Oceania	Landslide	17	486	20,315	2,466
	Average per event		28.6	1,195	145.1

Created on: 23 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

by country between 1974 and 2003. Even though drought itself generates less waste, it can create platform for further disasters like wild fire or epidemics.

13.12 Epidemic Disease

Epidemics would generate more biomedical waste than any other disaster. It could accompany other disaster like earthquake, tsunami and flood. The spread of pathogen by water, air, food, vector or any other means would result in sickness among large number of people.

Table 13.14 gives summarized table of epidemics sorted by continent from 1900 to 2011 and Fig. 13.19 shows the worldwide epidemic occurances between 1974 and 2003. Severe outbreaks of pathogenic avian influenza in birds resulted in human deaths. More than 250 million birds were killed or culled from 1997 to 2007, compared to 23 million in the last 40 years (Capua and Alexander 2004; Peiris et al. 2007).

Table 13.13 Summarized table of drought sorted by continent from 1900 to 2011

Area	Event	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	1	-	2,400,000	-
	Average per event		-	2,400,000	-
	Drought	275	844,143	330,651,357	5,419,593
	Average per event		3,069.6	1,202,368.6	19,707.6
Americas	Drought	123	77	65,133,841	20,811,139
	Average per event		0.6	529,543.4	169,196.3
Asia	Drought	149	9,663,389	1,668,036,029	31,739,865
	Average per event		64,855	11,194,872.7	213,019.2
Europe	Drought	38	1,200,002	15,482,969	21,461,309
	Average per event		31,579	407,446.6	564,771.3
Oceania	Drought	20	660	8,027,635	10,703,000
	Average per event		33	401,381.8	535,150

Created on: 22 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

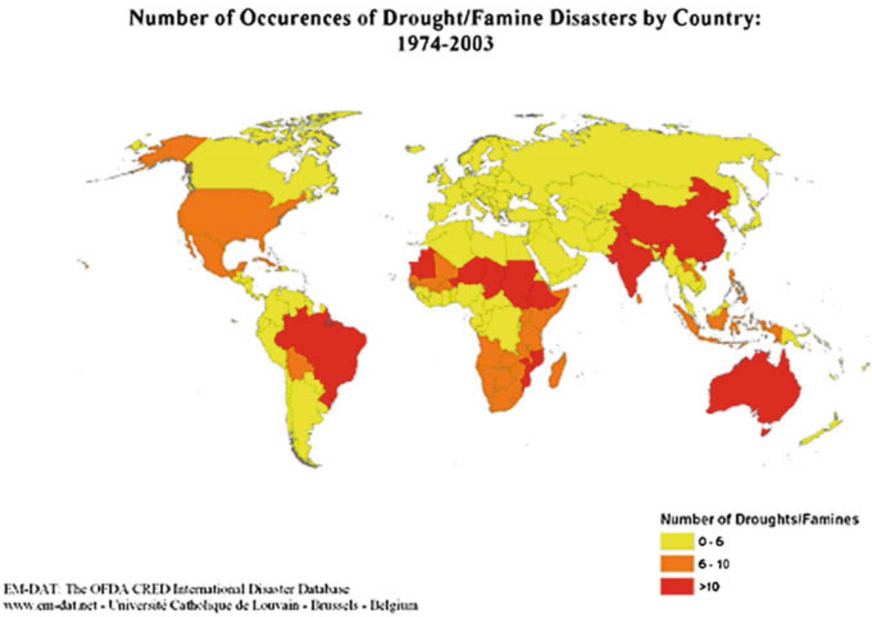

Fig. 13.18 Number of occurrences of drought/famine disasters by country: 1974–2003

Table 13.14 Summarized table of epidemics sorted by continent from 1,900 to 2011

Area	Events	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Unspecified	73	207,119	153,199	-
	Average per event		2,837.2	2,098.6	-
	Bacterial Infectious Diseases	501	226,619	2,321,005	-
	Average per event		452.3	4,632.7	-
	Parasitic infectious diseases	20	4,723	8,722,500	-
	Average per event		236.2	436,125	-
	Viral infectious diseases	147	23,889	1,324,870	-
	Average per event		162.5	9,012.7	-
Americas	Unspecified	8	8,693	100,206	-
	Average per event		1,086.6	12,525.8	-
	Bacterial infectious diseases	48	12,060	845,683	-
	Average per event		251.3	17,618.4	-
	Parasitic Infectious Diseases	6	104	518,403	-
	Average per event		17.3	86,400.5	-
	Viral infectious diseases	88	52,519	3,531,153	7
	Average per event		596.8	40,126.7	0.1
Asia	Unspecified	54	9,939	2,688,181	-
	Average per event		184.1	49,781.1	-
	Bacterial infectious diseases	117	5,674,671	778,442	-
	Average per event		48,501.5	6,653.4	-
	Parasitic infectious diseases	20	5,284	1,518,005	-
	Average per event		264.2	75,900.3	-
	Viral infectious diseases	141	839,173	3,088,762	-
	Average per event		5,951.6	21,906.1	-
Europe	Unspecified	6	2,500,000	1,575	-
	Average per event		416,666.7	262.5	-
	Bacterial infectious diseases	16	347	167,027	-
	Average per event		21.7	10,439.2	-
	Parasitic infectious diseases	3	47	18,000,344	-
	Average per event		15.7	6,000,114.7	-
	Viral infectious diseases	24	81	20,888	-

(continued)

Table 13.14 (continued)

Area	Events	Number of events	Killed	Total affected	Damage (000 US $)
	Average per event		3.4	870.3	-
Oceania	Bacterial infectious diseases	5	172	6,475	-
	Average per event		34.4	1,295	-
	Viral infectious diseases	13	7,026	11,838	-
	Average per event		540.5	910.6	-

Created on: 27 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

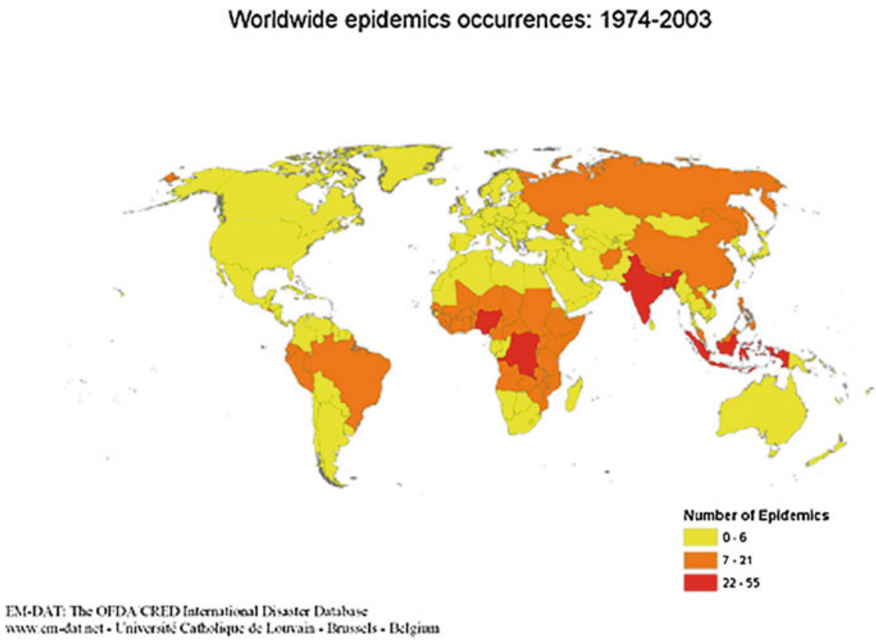

Fig. 13.19 Worldwide empidemics occurrences: 1974–2003

13.13 Hail Storms

Hailstorms or ice-storms are storms that generate hailstones which then fall on the ground. Ice storms will result in restricted access and power outages. Ice storms and severe snowstorms often cause problems that are similar to that of hurricanes resulting in significant damage to vegetation. Roads may be closed due to fallen

Table 13.15 Summarized table of major volcanoes sorted by continent from 1900 to 2011

Area	Event	Number of events	Killed	Total affected	Damage (000 US $)
Africa	Volcanic eruption	17	2,218	511,353	9,000
	Average per event		130.5	30,079.6	529.4
Americas	Volcanic eruption	79	67,858	1,463,577	2,168,697
	Average per event		859	18,526.3	27,451.9
Asia	Volcanic eruption	90	21,785	3,001,239	708,351
	Average per event		242.1	33,347.1	7,870.6
Europe	Volcanic eruption	12	783	26,224	44,300
	Average per event		65.3	2,185.3	3,691.7
Oceania	Volcanic eruption	23	3,665	259,900	110,000
	Average per event		159.3	11,300	4,782.6

Created on: 23 Dec 2011. Data version: v12.07
Source EM-DAT: the OFDA/CRED international disaster database
www.em-dat.net—Université Catholique de Louvain–Brussels–Belgium

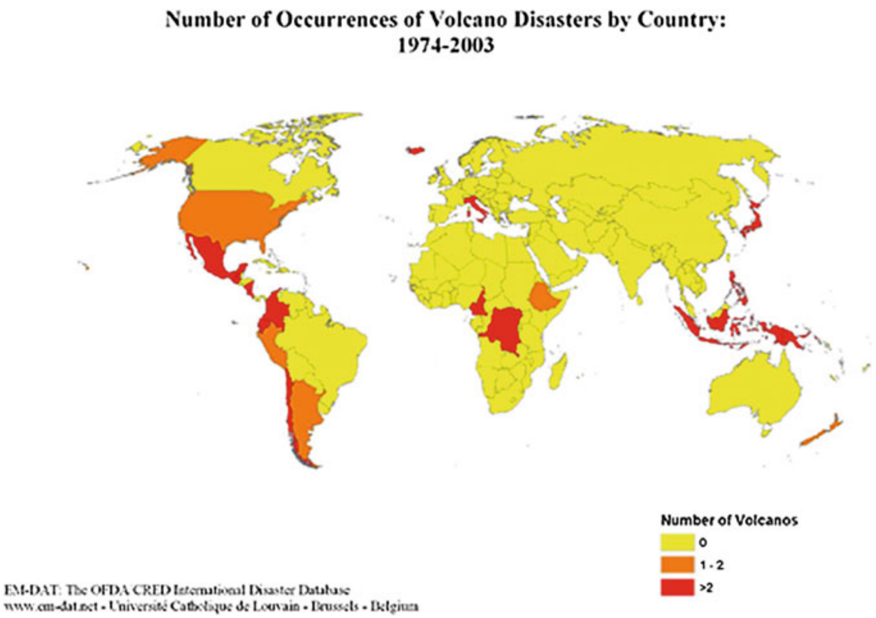

Fig. 13.20 Number of occurrences of volcanic disasters by country during 1974–2003

trees and branches. Power will be disrupted which are not easily repairable. Utility poles and wires will be severely damaged and become debris. Continued cold weather may hinder restoration of utilities. Thunderstorm in April 14, 1999 in Sydney, Australia was associated with large hailstones in size of grapefruit, melons, or cricket balls damaged 24,000 homes as well as 70,000 automobiles (EMA 2007).

13.14 Volcanoes

The waste of volcanoes comes from diverse sources including lava flows, lahars (mudflows with volcanic debris), blasts and projectiles and ash fallout. Mortality is low compared to other disaster types. The most lethal volcano in Colombia of 1985 killed 21,800 people in Armero due to the movement of a lahar from the del Ruiz volcano (Guha-Sapir et al. 2004).

Volcanic eruption results in rock fall or landslides. The size of debris can vary from few loose rocks from the crater rim of the volcano to large scale landslide. Debris during volcano can be cold or hot. Hot debris is formed due to of volcanic activity and cold debris is formed due to unstable slope.

Table 13.15 gives summarized table of volcanoes sorted by continents from 1900 to 2011 and Fig. 13.20 shows number of occurrences of volcano disasters by country from 1974 to 2003. Volcanic ash will be most widely distributed. It threats health and causes disruption of infrastructure and aviation. Electricity networks are vulnerable as volcanic ash has a tendency to adhere to line and insulators causing flashover. Heavy rain will wash ash precipitated on surfaces. Dry ash is not conductive but mist or light rain will decrease resistivity of ash layer. Wet ash will also cause collapse of structure due to increase in load on structure. Ash deposited onto roads and car parks will be washed into storm drains during heavy rain and lead to flooding problems. It can enter wastewater treatment plants and damage the treatment. Ash will reduce grip on paved surfaces and clog filters as well as brake systems of automobiles engines (Thomsan et al. 2011). Erruption of Mt. Ruapehu in 1996 for two days deposited more than seven million tons of ash on central North Island (Claire and Peter 2006). About 1,100 tons/km^2/month of ash was estimated to be deposited around Mt. Sakurajima (Yano et al. 1985). The eruption of Cerro Negro in the year 1992 near the city of Leon, Nicaragua distributed about 1.7 million tons of ash in an area more than 200 km^2.

13.15 Wind Storms

Windstorms often cover very wide areas resulting in significant deaths, injuries, and economic loss. Storm surges can tip water, oil and chemical tanks causing spills. Debris flows during rain storms on areas burned due to forest fire have no particular initiation source (Susan et al. 2008). Wastes during wind storms include building materials due to destruction of flood and wind-damage. This waste comprises of bricks, wood, concrete, asphalt, rocks/gravel, etc. Figure 13.21 shows number of occurrences of windstorm disasters by country from 1974 to

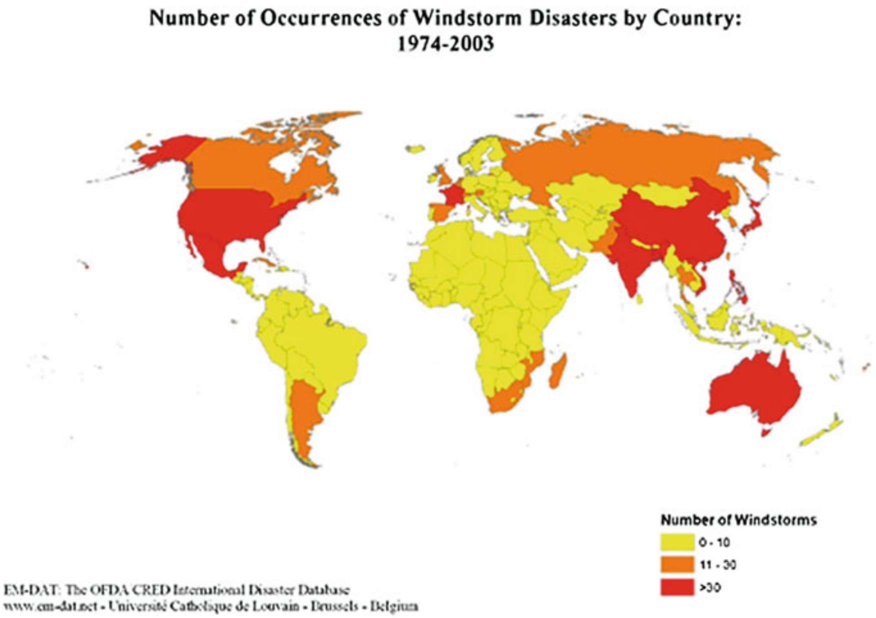

Fig. 13.21 Number of occurrences of windstorm disasters by country: 1974–2003

2003. The fatal windstorm of the in Bangladesh in 1991 killed 138,866. In many cases, flooding due to heavy rains and wind surges will have a greater impact on life and property than the wind itself. On an average each windstorm affected nearly 300,000 people even though a windstorm in China affected 100 million in 2002. Collapsing buildings and wind-strewn debris would account for many of the injuries during windstorms. Changing climate is increasing risk of storms and sea level rise. Managing HHW is a problem during debris cleanup. Degradable wastes from dead animals as well as spoiled food can quickly rot and the result in foul odors.

13.16 Waste Management

Disaster wastes are characterized by.

1. Waste due to damage caused to infrastructure, raw materials in industry, goods in shipyard, airports, warehouse, railway stations.
2. Quantity and quality of waste depends on development of disaster affected area. Disaster affected village would generate less contaminated waste compared to industrial area. The disaster in developing country may not be same as developed country as many of people would be living in make shift poorly built

Fig. 13.22 Waste sorted before despatching for recycling

housing in developing country. Within the country, waste is characterized by development of the area.

3. Quantity and quality depends on magnitude of disaster.
4. While disasters involving huge quantity water like flood/tsunami would result in more wet waste characterized by rotting and corroding material.
5. Disaster like war and terrorism would leave behind unexploded ammunition and shells used for ammunition, and.
6. Ash and coal may accumulate due to disaster involving fire and would be necessary to quench the fire before handling waste.

Good planning and management for response to disaster is necessary to reduce disruption (Gordon and Dion 2008). A good disaster waste management needs.

Development of plan ahead of disaster during city planning stage itself.
Procurement and maintenance of equipment and vehicles at regional level based on the type and frequency of past disasters.
Database of alternative collection and storage sites.

Figure 13.22 shows waste sorted before despatching for recycling. The waste streams generated during disasters include almost all types of waste like excessive unwanted donations, vegetative matter, emergency relief food packaging, hazardous waste, construction and demolition debris, waste from industry, waste from pre-disaster disposal sites, food waste, displaced rock and soil, damaged vehicles and vessels, WEEE, human and animal corpses, and biomedical waste.

Management of disaster waste will be carried out in three phases (Kuramoto 1995; Baycan and Petersen 2002): (1) emergency response, (2) recovery, and (3) rebuild. The phases are not distinct and the duration of each phase varies from location to location.

In terms of the waste management, the emergency stage involves the elimination of immediate threats to public health and safety (Reinhart and McCreanor 1999) and usually lasts between a few days and two weeks (Haas et al. 1977). Disaster would usually be associated with looting and rioting, slow road clearance, poor coordination, public health concerns, absence of people and resource, waste dumping by frustrated disaster victims, poor communication, slow home demolition, public complaints over inappropriate waste handling, decomposition of food and other degradable material.

13.16.1 Emergency Response

In emergency response, debris are managed to facilitate preservation of life, provision of emergency services, removing immediate public health and safety hazards. During recovery, waste management is carried out as part of restoring lifeline restoration and building demolition. Lastly in rebuild stage, wastes generated from disaster are used in re-construction. In this stage it is very essential that waste issues be indentified through media, publications and reconnaissance surveys. After identifying the issues, waste should be quantified, characterized and mapped before deciding priority of events for waste handling.

Prioritized action should include identification of temporary storage or disposal sites, optimal use of available resources, clearing transportation pathways as well as disposing infectious waste on priority.

Ownership of waste/material especially valuables like ornaments reusable soiled material in waste heap is an important issue. During this stage people often would proactively start picking valuable items on priority.

13.16.2 Recovery

The recovery phase can be affected by numerous issues including police investigations which are outside the control of waste management authority (Ekici et al., 2009). The rebuilding phase is a much longer process. As per Haas et al. (1977) the rebuilding phase duration could be as long as 10 years.

Improper temporary storage location like playgrounds, and rice fields are damaging to the environment as well as people's livelihoods, as observed in 2004 Indian Ocean Tsunami (Basnayake et al. 2006; Pilapitiya et al. 2006; UNDP 2006).

During this stage assessment and allocation of resources should happen in parallel to proper decontamination of site and disinfection of infected material.

Box 13.1 Case study of solid waste management after fire at Russell market, Bangalore

Russell market (Fig.13.23) of Bangalore, India, which hosts 480 shops caught fire on around 3.30 a.m., on 25th of February 2012 lasted till 7 a.m of destroying 174 shops in the 85-year-old structure. The fire was believed to have been caused due to electrical short circuit did not cause any loss of life. Twenty eight fire tenders fought the fire. The fire destroyed vegetable, fruit,

Fig. 13.23 Remains after a fire at Russell market, Bangalore, India

flowers, toys and knick-knack stores at the first as well as the ground floor. The remains were mainly partially burnt furniture, and burnt vegetable/fruits/flowers. The partially burnt furniture was recovered by owners for reuse where as the damaged vegetable/fruit/flowers were cleared by vehicles spatially meant to clear waste. The shops were given compensation by government to partially fulfil the damage as a result the market regained its activity after few of days.

Fig. 13.24 Waste spread in a disaster affected area

13.16.3 Rebuild

At this stage temporary storage of waste shall be moved to proper disposal site and recover the useful material for maximum extent. Disaster debris can be used as aggregate for concrete, building block and filling the low lying area. Large pieces of the metal component can be used by metallurgical industries. Plastic/glass waste can be recycled/reused after cleaning.

Temporary storage sites are commonly used in the management of disaster waste (Fig. 13.24). Temporary storage areas for recycling/processing are recognized as an important element by numerous authors (Johnston et al. 2009; USEPA 2008) as they provide additional time for segregating, recycling and disposing the waste.

Choice on disaster waste management need to consider factors such as: materials in existing recycling markets, the logistics involved, space requirements and associated land-use issues, economics of post-disaster recycling, and impact on environment. Projects which use disaster recycled materials may not achieve the same level of environmental and structural quality control as in peacetime (Charlott et al. 2011). Inappropriate location of temporary storage sites will be potentially damaging to the environment and people's livelihoods.

13.16.4 Waste Transportation

Waste transportation during a disaster would depend on the type of the disaster. Some disaster (like earthquake, tsunami, flood, and landslide) would destroy/block transportation network. Other disaster (like draught and epidemics) would not damage the transportation system, but the challenge of handling waste not predicted/foreseen would affect economy and budget of government.

13.16.5 Waste Reuse/Recycle

Many components of disaster waste can be recycled. Examples of recycling disaster waste include soil for landfill cover, aggregate for concrete and plant material for compost (Channell et al. 2009). The benefit of recycling disaster debris is evident in many past disaster cleanups: Marmara earthquake (Baycan and Petersen 2002; Baycan 2004), Kosovo (DANIDA 2004), Northridge Earthquake, US, 1994 (Gulledge 1995; USEPA 2008), Lebanon (Jones 1996), Great Hanshin-Awaji earthquake (Kobayashi 1995), Indian Ocean Tsunami, Thailand and Sri Lanka (Basnayake et al. 2005; UNDP 2006).

The benefits include: (1) reduction of landfill space used, (2) reduction of the quantity of raw material used in re-build, (3) revenue from recycled debris, (4) reduction in transportation for raw materials and debris, (5) easy access for post disaster recovery activities, and (6) job creation.

Barriers and opportunities to recycling of construction and demolition (C&D waste) are well documented (Kartam et al. 2004; Blengini 2009; Kofoworola and Gheewala 2009; Skinner 1995; Reinhart and McCreanor 1999). Potential barriers to C&D recycling after a disaster include the time to collect and manage the materials, the unavailability of specific processing equipment (Baycan and Petersen 2002), difficulty to physically separate the materials (Lauritzen 1998; Baycan 2004), the lack of willingness to use waste materials in rebuild (Lauritzen 1998), absence of disposal sites (Lauritzen 1998), expenses relative to other disposal methods (Solis et al. 1995), and nonavailability of markets to use large quantities of material (Solis et al. 1995; Lauritzen 1998).

Conversion of waste to energy has been proposed by Yepsen (2008) as a disaster waste treatment option with limitations like high shipping costs and limited markets. Small scale waste to energy conversion was done in the USA for waste generated during the hurricanes Katrina, Rita, Charley, Frances and Jeanne (USEPA 2008).

13.16.6 Waste Disposal

Problem of waste disposal can vary from disaster to disaster. Vehicles are often moved to great distances and may block roads. Leakage of gasoline, diesel, and other hazardous chemicals can change the properties of waste there by and converting non hazardous waste into hazardous waste. Disposal of hazardous waste has been recognized as problematic in several disasters like Indian Ocean tsunami (Pilapitiya et al. 2006) and hurricane Katrina (Dubey et al. 2007). The removal and disposal of waste are complicated due to ownership and insurance issues there by slowing down cleanup as well as recovery efforts (Mike et al. 2005).

Combustible debris is intentionally burned in many parts of the world to reduce its volume. However, disaster debris can inadvertently catch fire due to spontaneous combustion or lightning by threatening nearby structures and forests.

Waste quantities exceed permanent disposal site capacities in numerous large scale disasters, (Petersen 2006; USEPA 2008). Temporary waste disposal sites were used as in the case of Marmara earthquake (Baycan 2004).

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Chapter 14
Solid Waste and Livelihood

Livelihood is nothing but the activity to sustain day to day life. It varies according to different social, ecological, geographical, climatic contexts. It also depends on resources, social relationships, risks, uncertainties, changing life style, epidemics, market risk, inflation, and competition.

Conventionally managing solid waste is not considered as the main livelihood. But as would be discussed in subsequent paragraphs nearly one percent urban settlement in many countries depends on solid waste. The population depending on solid waste includes waste pickers (rag pickers or scavengers), scrap dealers, garbage collectors, truck drivers, waste handlers, disassembles, recyclers, merchants of finished goods.

Informal waste recycling is characterized by small-scale, low cost, low risk, labour intensive enterprises. Figure 14.1 shows a series of jobs created by waste management activities. Most of the low-income nations have large informal sectors due to large number of poor as well as un-employed population (Akiko and Mitsuo 2011). Livelihoods in urban areas can be classified as formal and informal. According to Becker (2004) share of informal workers varies from 40 to 60 % of urban employment in Asia. About 120 thousand people are occupied in the informal recycling trade in Dhaka, Bangladesh which has a population of 12 million (UN-Habitat 2010). The developing countries are increasing the recovery of materials from solid waste due to the advantages of recycling.

It is often difficult to gather the number of people who depend on waste for livelihood in developing countries. Livelihoods in urban areas can be classified as formal and informal. Informal sector shows a high ability to react to threats/challenges and is characterized by a high presence of economically marginalized workers with low wages, lack of access to institutional credits, and dignity of labour (Pornima and Lakshmi 2009). Figures 14.2a and b show some examples of livelihood that depend on solid waste. Privatising waste dumps would restrain access for waste pickers (Rachel and Chasca 2003).

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Environmental Science and Engineering, DOI: 10.1007/978-3-642-28681-0_14,

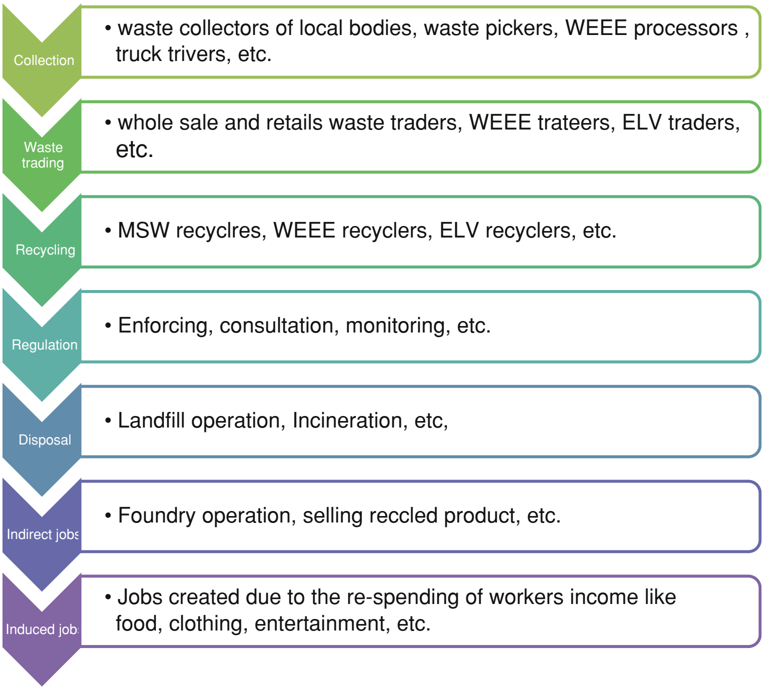


Fig. 14.1 A series of jobs created by waste management activity

As per the data published by HSE (2004), the United Kingdom, which generates 50 million tonnes of commercial waste, 30 million tonnes of industrial waste, and about 30 million tonnes of municipal waste, employs 160,000 workers in the waste management sector. Among these about 120,000 workers are employed in the private sector. The waste sector in the USA comprises of about 27,028 organizations employing some 367,800 employees (Edward 2001). The number of people engaged in the waste sector increased from 5,658 to 8,749 between 2000 and 2009 in Austria (Ursula and Karin 2011). As per (Schneider 1998), informal economy in Austria and Germany makes an important contribution to the wealth of these countries. Informal collectors and recyclers handle majority of e-waste (Tong et al. 2004; Hicks et al. 2005; Kojima et al. 2009). WEEE being one of the major sources of heavy metals in municipal waste in the Asian developing nations (Bertram et al. 2002) as these countries generate domestic e-waste and receive used information technology (IT) equipments devices from abroad (Brigden et al. 2008). WEEE in China is mostly recycled by the informal sector. Such practices expose workers to health problems (Williams 2005). In Zabbaleen's suburb of Cairo 50,000 people live and process waste (Richard et al. 2002). The number of people employed in the USA in waste management and remediation services rised from 0.22 to 0.37 million during 1990–2012 (BLS 2012).

Ragpickers		Rag or waste pickers can be observed in almost all part of the world. In some of the developing countries they form 0.25 to 0.50% of a city's population.
Scrap dealers		Scrap dealers mostly buy waste from waste pickers, waste collectors and generaters. In some of the developing countries they form the 0.25 to 0.50% of city population. They pay to waste generators, collectors, and waste pickers.
Waste collectors		Waste collectors are mostly employees of the local body responsible for solid waste management. Sometimes local body can outsource the task to private agency or NGO. They are usually paid by waste generators.
Sweepers		Sweepers are mostly employees of the local body responsible for solid waste management. Some times local body can out source the task to private agency or NGO.
Truck drivers		Truck drivers and other crews in truck are mostly employees of the local body responsible for managing solid waste. Sometimes the local body can outsource the task to private agency or NGO.

Fig. 14.2 Livelihood and solid waste

The recovery and recycling by waste pickers can save energy. For example, recycling some metals requires 3–5 % of the energy required to obtain from ores. A study in Mexico revealed that nearly 353,000 tons of waste is collected by 3,000 waste collectors in a year. They usually recover recyclables present in the waste. Brazil has nearly 500 waste picker cooperatives with approximately 60,000 members.

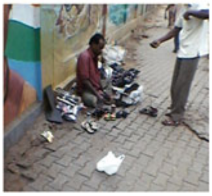
Waste handlers		Waste handlers are employees of organisation responsible for treatment and disposal agencies. They may also recycle the waste.
Dis-assemblers		Manual disassemplers are specialised waste handlers who may also act as recycler. Their specialisation vary from disassembling WEEE to old/damaged vehicles/machineries.
Recyclers		Recyclers include cobblers like the one shown in picture who is mending old footware. Other recylers include metallugical industries which melt scrap metal for manufacturing metal items and plastic industry which melt plastic for manufacturing new plastic articles.
Itinerant waste buyers		Itinerant waste buyers are people who move from place to place buying (or bartering for) recyclable and reusable waste materials. The person in this picture is trying to barter old cloths for stainless steel utensils.
House keeping staff		Housekeeping staff like the one shown in adjacent depend solely on housekeeping and waste handling in spite of poor hygienic work condition and low pay.

Fig. 14.2 Livelihood and solid waste (Continued)

In Mumbai, India more than 30,000 rag pickers have created more than 400 microenterprises for processing waste materials. Buenos Aires in Argentina has more than 40,000 rag pickers while Jakarta in Indonesia has approximately 37,000 waste pickers (Medina 2007).

Apart from the livelihood during normal period, activities during disaster would alos create employment opportunities during recover stage. 1,000–1,500 people worked with 60 dump trucks as well as other heavy equipment for more than one year during tsunami rehabilitation in Kota Banda Aceh, Indonesia (UNDP and BRR NA).

As per ECDGE (2000), employment linked to waste management in Europe represents about 120,000 FTE (full time equivalent jobs) annually. On a European level 70 % for recycling of key materials would generate up to 322,000 direct jobs across the EU27 there by recycling a further 115 million tonnes of paper, plastic, wood, glass, metals, and textiles etc. and thereby could create 160,900 new indirect jobs as well as 80,400 induced jobs (Friends of Earth 2010).

Like any other sector, the waste sector will also create indirect jobs (like foundry operation, recycled product selling etc.) and induced jobs (jobs created due to the re-spending of workers income like food, clothing, entertainment etc.). For every direct job created in the waste sector, 1.2 'indirect' jobs as well as 1.3 'induced' jobs were created in the US (Friends of Earth 2010). In the USA, about 33.4 % waste is recovered for recycling as well as composting (US EPA 2008) thereby employing over 1.1 million people at 56,000 public and private facilities in 2001 (US EPA 2002). Steel mills, plastics converters as well as iron and steel foundries account for 50 % of all recycling industry jobs (UNEP, ILO, IOE, ITUC 2008). Remanufacturing in areas like motor-vehicle components, compressors, office furniture, photocopiers as well as laser toner cartridges employs about 480,000 people (Remanufacturing Institute 2003). As on June 2010, 2,667 businesses/organisations of waste management services employed 26,812 people in Australia (ABS 2011).

14.1 Rag Pickers

The changing global economy has resulted in new demands on economies, which has a negative effect on natual resources and employment. In the third world cities improper law enforcement, corruption, population and immigration have resulted in creation of inner-city slums, and inefficient collection of waste. In such situation poor and marginalized people will choose waste picking for income. Waste or rag pickers who are also referred as junk-men have been living and scavenging urban waste since waste materials are considered as common property. The quanity of waste picked and sorted by them vary from 20 to 50 kg/day depending on the age, health and availability of waste.

Some scavengers self-identified as freegans aim to avoid ecological impact by living only from food items discarded by super markets. Traditionally, most people who resort to waste picking do so out of economic necessity. In many cities a specialized waste pickers referred to as *binners* or bottle collectors search solid waste only for recyclable bottles that is redeemed for deposit value.

Fig. 14.3 A colony of waste pickers

Figure 14.3 shows a colony of waste pickers. The waste pickers at many places include runaway children and unemployed labourers. Since waste picking does not require specific skills and strengths it is easily adopted by females and children. Women bring children along due to the advantages associated with increased labour.

Scavengers occur in both developed as well as developing countries.

Waste pickers can (re)appear during war and severe economic crises (Anne et al. 2006). During the United Nations-sanctioned trade embargo on Haiti, waste pickers particularly looked for pre-packaged military meals and metal parts discarded by the US peacekeepers (Medina 1997). When the Bosnian Serbs sieged Sarajevo, some of their citizens survived by searching food and wood in refuse (Anne et al. 2006).

(Rosario 2004) considers waste pickers as ‘semi-visible entities’ and industries recycling waste are ‘unseen operations’ in the urban scenario. Waste pickers have been scratching waste since the cities in Europe and North America first started collecting waste in the 1880s (Melosi 1981). Urban lumberjacking is a particular type of scavenging where the focus is to salvage wood. Dumpster diving (term used in the USA) is known as skipping in the UK and is the practice of sifting through solid waste to find items which will be useful for scavengers. Sao Paulo, Brazil has an estimated 20,000 waste pickers (Anne et al. 2006). In Bogota (Colombia) about 30,000–50,000 people earn by picking recyclables from waste (Hardoy et al. 1992). Medina (2000) reported an estimated 40,000 cartoneros (informal resource recovers) operating in Greater Buenos Aires, Argentina (Medina 2000) and (Reynals 2002) reported that 100,000 people live directly from income generated from the cartoneros. In Cairo, the waste pickers are called “zebaleen” and Paris has a large number of scavengers, known as les glaneurs. Gujarat state in India has around 100,000 rag pickers out of which Ahmedabad city accounts for about 30,000 (Kamala et al. NA). Delhi in India has nearly 100,000 waste pickers and Pune has around 6,000 of them (Chikarmane 2001). Bangalore, another city in India, has an estimated 35,000 waste pickers (Globenet NA) and Mumbai has 25,000 waste pickers (Karmayog NA) whereas Karachi (an Pakistan) had 20,000 waste pickers (Ali et al. 1993). While 300 tons are recycled by the rag pickers in Dhaka of Bangladesh, about 700 rag pickers engage themselves in waste picking in Vietnam (APO 2007).

The waste pickers can be beneficial to society as their act can greatly reduce recycling cost. But on the other hand, since most of them are uneducated they usually litter around. They will recycle anything and everything as long as they get financial returns and hence they collect and sell syringes and waste cotton from hospitals thereby recycling infection. Privatising waste dumps would restrict access for rag pickers whereas formal recycling of garbage would increase competition. Waste pickers often face harassment which includes verbal and physical abuse, false accusation and imprisonment. They are often exposed to viral infections, respiratory disorders, skin infections and injury due to sharp object present in the waste. Many people in the developing world start their careers as waste pickers or as child-labours in waste handling business. While some children help their parents in segregation of waste at home, others would accompany their parents during waste picking. There are other social reasons for people entering into waste picking as a profession. Many homeless orphans who cannot take up other jobs will easily take up waste picking and selling. The people who have left small jobs due to work place violence will also take up rag picking. Rag picking usually prevails in large urban body tather than rural area due to potential for waste to pick. The rag pickers would often form slums (Fig. 14.2) and usually conclude the life without financial prospectus.

On-site scavenging obstructs landfill operations in many developing countries. In Accra, Ghana, rag pickers sorted through waste before and immediately after unloading. They also often prevented the operation of compactor (Lars and Gabriela 1999). It is also common practice in some places with high potential like waste dumps no new waste pickers are allowed by established pickers. Sometimes waste pickers also have to pay bribe to government officials or local politicians who control the area. Waste picking is also only an option for unemployed people who migrate to urban as they will not have any qualification, reference and recommendations to join government, multinational or local companies. The waste pickers walk in the streets of urban area collecting waste that can be reused. In many instances the income earned will be more than that of wages in rural area where people cannot afford to pay wages especially if the village is affected by disasters.

14.2 Scrap Dealers

Number of scrap dealers is difficult to assess as they range from street level to international online scrap dealers. Scrap dealers does not depend solely on rag pickers for waste sourcing. Many of the residences, industries and waste collectors would also contribute scrap to these dealers. Number of scrap dealers would come down drastically with development as there would be more choice of business or carrier compared to scrap dealing.

Fig. 14.4 Livelihood pyramid with respect to SWM in Pune, India [based on data presented by Poornima and Lakshmi (2009)]

Scrap business is still in unorganized sector in many developing countries. In the UK, wholesale scrap and waste business employs about 11,600 people. Recycling business of metal waste and scrap in the UK employs about 7,500 and recycling business of non-metal waste and scrap employs around 6,400 (HSE 2004). Figure 14.4 shows livelihood pyramid with respect to SWM in Pune, India (based on data presented in Poornima and Lakshmi (2009). The average buyer in Bombay (now Mumbai), India traded 39 tonnes of recyclables every month as against 382 tonnes in case of wholesaler who buy material from buyer (Pieter et al. 1996).

14.3 Waste Collectors

Waste collectors differ from that of waste picker in the context that they are hired by an authority of an agency to collect waste from definite source. The source could be houses, offices or commercial/industrial establishments. The quantity of waste collected varies depending area of operation.

Dhaka with a population of nearly 7.5 million people produces about 4,000 t/d of solid waste and nearly 50 % of its waste remains uncollected by the Dhaka City Corporation (DCC) authority. About 100,000 people are directly associated with the collection, transportation, disposal, recycling, reusing and composting activities (Nazrul and Salma 2004). DCC has 370 collection vehicles as well as around 7,156 cleaners engaged for street sweeping and the collection of waste found in lakes (APO 2007).

In Dar es Salaam, Tanzania, privatization efforts have created more than 1,500 jobs (Saskia et al. 2000). Singapore had about 350 licensed private waste collectors in 2002 (Renbi and Mardina 2002).

Bangalore, India which has a population of 7.8 million generates about 3,000 t/d of solid waste. It has 11,650 primary collectors (for door to door collection), 600 truck drivers (for secondary collection assisted by one more person in each truck) and 14,300 sweepers. The city has four municipal solid waste facilities employing 50—100 persons in each plant.

Total staffs for solid waste management in Kathmandu, Laithpur, Bhaktapur, Madyapur, and Kirthipur of Nepal are 1262, 211, 217, 23, and 6 respectively (JICA 2004).

14.4 Sweepers

Sweeping is one of key functions of local bodies across the world. Sweeping is required not only to clean litters thrown by people but it is also required to clean leaves shed by trees and dust accumulated on road.

Sweepers are less in the developed world due to use of sweeping machines. A sweeper can usually sweep 500 m/d and any additional responsibility to clean extra stretch would result in inefficiency. Street sweeping by sweeping machines are becoming popular even in the developing world due to their efficiency. But many governments still prefer manual labour to create jobs to help uneducated citizens. With the growth of economy, people tend to take up better jobs at which time the sweeping work can be shifted to machines.

As per APO (2007) the number of sweepers per 1,000 people in India is.

- 1.30–3.80 for cities with population above 10 million,
- 1.57–2.11 for cities with population between 2 and 10 million, and
- 0.15–3.51 for cities with population between 1 and 2 million.

This means roughly 0.1–0.3 % urban populations in developing world would make living by sweeping in urban population.

While the public roads and streets of Delhi, India are swept by 49,000 sweepers, Dhaka of Bagladesh has about 7,156 street sweepers (APO 2007). Total sweeping staff in the Municipal Corporation of Delhi and New Delhi Municipal Council is in ratio of 1:216 persons and 1:326 persons, respectively (IL&FS Ecosmart NA).

14.5 Truck Drivers

Number of truck drivers depends on the quantity of waste generated. Irrespective of the developmental stage of a country large numbers of truck drivers are required to haul the waste towards disposal points. The truck drivers are employed for transporting MSW, hazardous waste, WEEE, biomedical waste and recyclables. They are part of the system in both the developed and developing world.New York, USA, has approximately 5,550 trucks for refuse collections (DSNC NA). The number of trucks in Nairobi, Mosumba, Kisumu, Nakaru and Elderest of Kennya are 66,34,28,25 and 28 respectively (Rotich et al. 2006). Table 14.1 gives

Table 14.1 Number of trucks used for hauling MSW in selected cities

City/Country	Population (in millions)	Number of trucks used for hauling MSW	Reference
Newyork, USA	20.0	5,550	DSNC (NA)
Nairobi, Keenya	2.0	66	Rotich et al. (2006)
Mosumba, Keenya	0.7	34	Rotich et al. (2006)
Kisumu, Keenya	0.5	28	Rotich et al. (2006)
Nakuru, Keenya	0.3	25	Rotich et al. (2006)
Eldorest, Keenya	0.2	28	Rotich et al. (2006)
Chennai, India	6.0	661	Esakku et al. (2007)
Pudong, China	2.8	200	Zhu et al. (2009)
Dhaka, Bangaladesh	10.0	370	APO (2007)
Khon Kaen, Thailand	1.3	27	APO (2007)

the number of trucks used for hauling MSW in selected cities. Each truck will have driver and usually accoumpnied by another staff.

14.6 Waste Handlers

Waste handlers are people who are employed (by municipalities and private agencies) or self employed for collection treatment and disposal of waste. Their number depends on the use of mechanical equipment. The developed countries uses sophisticated collection vehicles and systematic segregation/treatment facilities (Fig. 14.5) and hence require less number of people for handling waste.

14.7 Manual Waste Dis-assemblers

Manual dis-assemblers are those employed in waste processing units like WEEE treatment facilities, ship breaking industry, old machine disassemblers etc., wherein the people dis-assemble useful components from waste machines/ equipments.

Out of many informal e-waste processing locations Guiyu and Taizhou are the prominent ones in China. With a population of 150,000, Guiyu has nearly 300 companies as well as 3,000 workshops engaged in WEE recycling work (Xinget al. 2009). 460,000 jobs are supported by scrap recycling industry in the USA (ISRI NA). Ship breaking and recycling industry (SBRI) in Bangladesh, India, and Pakistan account for 70–80 % of the international SBRI. Each country employs from 8,000 to 22,000 in the ship recycling yards and about 200,000 in the shops, supply chain, and re-rolling mills (Maria et al. 2010).

Fig. 14.5 Waste handlers

14.8 Waste Recyclers

Recyclers are people engaged in recycling the waste like bottles and cartoon boxes through systematic or informal setup. Waste can be categorised as non-recycleble or recyclable as shown in Fig. 14.6**.** The recyclers collect recyclable waste objects from scavengers and factories and sell it to recycling industries after segregating it to paper, metal, and plastic. Some larger recycling operators deposit money with small waste buyers to enable them to have funds to buy waste from the waste pickers.

Waste management in Australia is carried out by government enterprises and private firms. The local government is usually responsible for waste collection, transportation as well as providing landfill facilities. Recycling is usually carried out by the private sector. Based on some statistics from Australian Bureau of Statistics (2008) employment generated in Australia is depicted in Fig. 14.7.

As per Environment Victoria (2009), jobs are created for incinerating, landfilling and recycling 10,000 tonnes of waste is 1, 6 and 36, respectively.

14.9 Itinerant Waste Buyers

In addition to the stationary buyers many cities have itinerant waste buyer (IWB). Itinerant waste buyers are people who move around streets buying (or bartering for) reusable and recyclable waste materials. These IWBs are usually mobile and go from doors to doors to buy wastes from shops, houses or offices. The materials they buy/barter vary from candies, sweat meats to plastic articles and metal utensils. The IWBs form an important part of the waste recycling system in the Indian cities and rural areas. IWBs can be often seen wandering from village to village in bicycle (bike) in many Indian villages, towns.

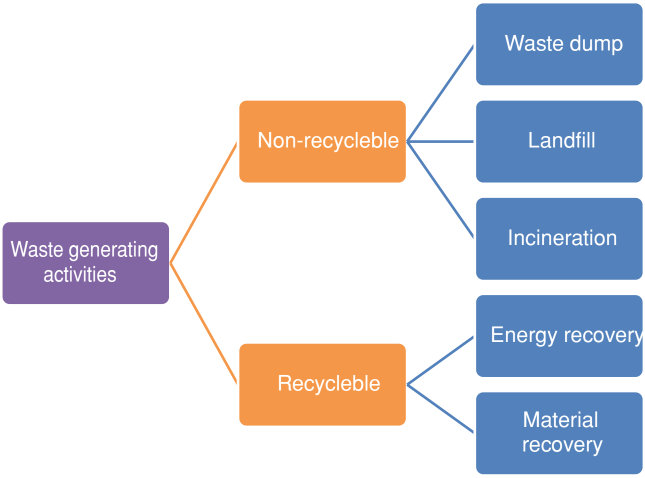


Fig. 14.6 Waste categorization based on destination

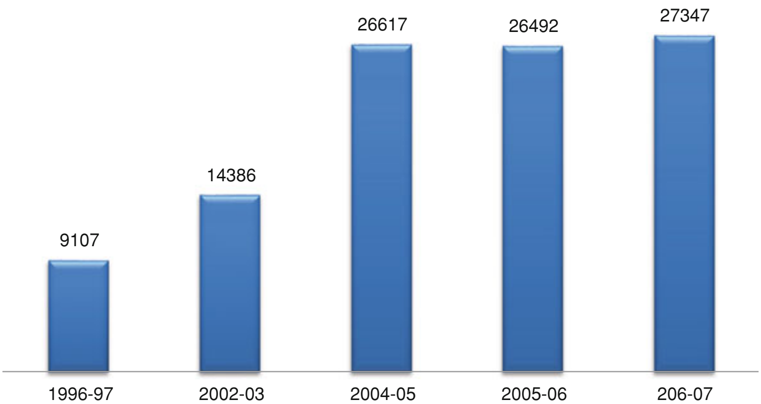


Fig. 14.7 Employment in waste collection, treatment and disposal services in Australia (based on data published by Australian Bureau of Statistics 2008)

The items collected by them mainly comprise of papers, plastics, metal scraps, and glass bottles which are sold to scrap buyers/dealers. The IWBs obtain waste before it is contaminated. IWBs do not compete with waste pickers and are independent operators or employees of the scrap dealers. The IWB collects nearly 40 kgs of recyclable per day. Even though they are common in Indian cities, presence of IWBs in an area with high rise building is minimal as they are not usually allowed in these buildings due to security reasons.

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Appendix

Radioisotope material with half life period

Radio isotope	Half-life
Actinium-225	10.0 days
Actinium-227	21.773 years
Actinium-228	6.13 h
Iodine-132	2.4 h
Rhodium-105	36.0 h
Xenon-133	5.3 days
Barium-140	12.8 days
Cerium-144	284 days
Cesium-137	30 years
Carbon-14	5,730 years
Uranium-234	250,000 years
Uranium-235	704,000,000 years
Uranium-238	4,470,000,000 years
Helium-4	12,500,000,000 years
Americium-241	432.2 years
Americium-242	16.02 h
Americium-242m	152 years
Americium-243	7,380 years
Antimony-124	60.20 days
Antimony-125	2.77 years
Antimony-126	12.4 days
Antimony-126m	19.0 min
Antimony-127	3.85 days
Argon-41	1.827 h
Astatine-217	0.0323 s
Astatine-218	2 s
Barium-137	2.552 min
Barium-139	82.7 min
Barium-140	12.74 days

Radio isotope	Half-life
Barium-141	18.27 min
Barium-142	10.6 min
Berryllium-10	1,600,000 year
Berrylium-7	53.44 days
Bismuth-210	5.012 days
Bismuth-211	2.14 min
Bismuth-212	60.55 min
Bismuth-213	45.65 min
Bismuth-214	19.9 min
Bromine-82	35.30 h
Bromine-83	2.39 h
Bromine-84	31.80 min
Cadmium-113m	13.6 years
Cadmium-115m	44.6 days
Calcium-41	130,000 years
Calcium-47	4.53 days
Californium-252	2.638 years
Carbon-11	20.38 min
Carbon-14	5,730 years
Cerium-141	32.50 days
Cerium-143	33.0 h
Cerium-144	284.3 days
Cesium-134	2.062 years
Cesium-134m	2.90 h
Cesium-135	2,300,000 years
Cesium-136	13.1 days
Cesium-137	30.0 years
Cesium-138	32.2 min
Chromium-51	27.704 days

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Radio isotope	Half-life
Cobalt-56	78.76 days
Cobalt-57	270.9 days
Cobalt-58	70.8 days
Coblat-60	5.27 years
Copper-61	3.408 h
Copper-64	12.701 h
Curium-242	162.8 days
Curium-243	28.5 years
Curium-244	18.11 years
Curium-245	8,500 years
Curium-246	4,730 years
Curium-247	15,600,000 years
Curium-248	339,000 years
Europium-152	13.33 years
Europium-154	8.8 years
Europium-155	4.96 years
Europium-156	15.19 days
Fluorine-18	109.74 min
Francium-221	4.8 min
Francium-223	21.8 min
Gadolinium-152	1.08E14 years
Gallium-67	3.261 days
Gold-198	2.696 days
Holmium-166m	1,200 years
Hydorgen-3	12.35 years
Indium-111	2.83 days
Indium-113	1.658 h
Indium-115	5,100,000,000,000,000 years
Iodine-123	13.2 h
Iodine-125	60.14 days
Iodine-129	15,700,000 years
Iodine-130	12.36 h
Iodine-131	8.04 days
Iodine-132	2.30 h
Iodine-133	20.8 h
Iodine-134	52.6 min
Iodine-135	6.61 h
Iridium-192	74.02 days
Iron-55	2.7 years
Iron-59	44.53 days
Krypton-83m	1.83 h
Krypton-85	10.72 years
Krypton-85m	4.48 h
Krypton-87	76.3 min
Krypton-88	2.84 min

Radio isotope	Half-life
Lanthanum-140	40.272 h
Lanthanum-141	3.93 h
Lanthanum-142	92.5 min
Lead-209	3.253 h
Lead-210	22.3 years
Lead-211	36.1 min
Lead-212	10.64 h
Lead-214	26.8 min
Lead-214	26.8 min
Manganese-52	5.591 days
Manganese-52m	21.1 min
Manganese-54	312.5 days
Manganese-56	2.579 h
Manganese-57	36.08 h
Mercury-197	64.1 h
Mercury-203	46.60 days
Molybdenum-93	350 years
Molybdenum-99	66.0 h
Neodymium-147	10.98 days
Neptunium-237	2,140,000 years
Neptunium-238	2.117 days
Neptunium-239	2.355 days
Neptunium-240	65 min
Neptunium-240m	7.4 min
Nickel-59	75,000 years
Nickel-63	96 years
Nickel-65	2.520 h
Niobium-93m	13.6 years
Niobium-95	35.15 days
Niobium-95m	86.6 h
Niobium-97	72.1 min
Niobium-97m	60 s
Nitrogen-13	9.97 min
Nitrogen -16	7.13 s
Oxygen-15	122.24 s
Palladium-107	6,500,000 years
Palladium-109	13.427 h
Phosphorus-32	14.29 days
Plutonium-238	87.74 years
Plutonium-239	24,065 years
Plutonium-240	6,537 years
Plutonium-241	14.4 years
Plutonium-242	376,000 years
Plutonium-243	4.956 h
Plutonium-244	82,600,000 years
Polonium-210	138.38 days

Radio isotope	Half-life
Polonium-211	0.516 s
Polonium-212	0.305 µs
Polonium-213	4.2 µs
Polonium-214	164.3 µs
Polonium-215	0.00178 s
Polonium-216	0.15 s
Polonium-218	3.05 min
Potassium-40	1,270,000,000 years
Potassium-42	12.36 h
Potassium-43	22.6 h
Praseodymium-143	13.56 days
Praseodymium-144	17.28 min
Praseodymium-144m	7.2 min
Promethium-147	2.6234 years
Promethium-148	5.37 days
Promethium-148	41.3 days
Promethium-149	53.08 h
Promethium-151	28.40 h
Protactium-231	3,280,000 years
Protactium-233	27.0 days
Protactium-234	6.70 h
Protactium-234m	1.17 min
Radium-223	11.434 days
Radium-224	3.66 days
Radium-225	14.8 days
Radium-226	1,600 years
Radium-228	5.75 years
Radon-219	3.96 s
Radon-220	55.6 s
Radon-222	3.824 days
Rhenium-187	50,000,000,000 years
Rhodium-103m	56.12 min
Rhodium-105	35.36 h
Rhodium-106	29.9 s
Rubidium-86	18.66 days
Rubidium-87	47,000,000,000 years
Rubidium-88	17.8 min
Rubidium-89	15.2 min
Ruthenium-103	39.28 days
Ruthenium-105	4.44 h
Ruthenium-106	368.2 days
Ruthenium-97	2.9 days
Samarium-147	106,000,000,000 years

Radio isotope	Half-life
Samarium-151	90 years
Samarium-153	46.7 h
Scandium-44	3.927 h
Scandium-46	83.83 days
Scandium-47	3.351 days
Scandium-48	43.7 h
Selenium-75	119.78 days
Selenium-79	65,000 years
Silver-110	24.6 s
Silver-110m	249.9 days
Silver-111	7.45 days
Sodium-22	2.602 years
Sodium-24	15.00 h
Strontium-85	64.84 days
Strontium-87m	2.81 h
Strontium-89	50.5 days
Strontium-90	29.12 years
Strontium-91	9.5 h
Strontium-92	2.71 h
Sulfur-35	87.44 days
Technetium-101	14.2 min
Technetium-99	213,000 years
Technetium-99m	6.02 h
Tellurium-125m	58 days
Tellurium-127	9.35 h
Tellurium -127m	109 days
Tellurium-129	69.6 min
Tellurium-129m	33.6 days
Tellurium-131	25.0 min
Tellurium-131m	30 h
Tellurium-132	78.2 h
Tellurium-133	12.45 min
Tellurium-133m	55.4 min
Tellurium-134	41.8 min
Terbium-160	72.3 days
Thallium-201	73.06 h
Thallium-207	4.77 min
Thallium-208	3.07 min
Thallium-209	2.20 min
Thorium-227	18.718 days
Thorium-228	1.913 years
Thorium-229	7,340 years
Thorium-230	77,000 years
Thorium-231	25.52 h
Thorium-232	14,100,000,000 years
Thorium-234	24.10 days

Radio isotope	Half-life
Tin-119m	293.1 days
Tin-123	129.2 days
Tin-125	9.64 days
Tin-126	100,000 years
Tungsten-181	121.2 days
Tungsten-185	75.1 days
Tungsten-187	23.9 h
Uranium-232	72 years
Uranium-233	159,000 years
Uranium-234	244,500 years
Uranium-235	703,000,000 years
Uranium-236	23,400,000 years
Uranium-237	6.75 days
Uranium-238	4,470,000,000 years
Uranium-240	14.1 h
Vanadium-48	16.238 days
Xenon-131m	11.9 days
Xenon-133	5.245 days
Xenon-133m	2.188 days
Xenon-135	9.09 h
Xenon-135m	15.29 min
Xenon-138	14.17 min
Ytterbium-169	32.01 days
Yttrium-90	64.0 h
Yttrium-91	58.51 days
Yttrium-91m	49.71 min
Yttrium-92	3.54 h
Yttrium-93	10.1 h
Zinc-65	243.9 days
Zinc-69	57 min
Zirconium-93	1,530,000 years
Zirconium-95	63.98 days
Zirconium-97	16.90 h

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Glossary

Absorption Assimilation of molecules of a substance into the physical structure of a solid without chemical reaction

Absorption capacity A measure of the extent of a material that can be absorbed by another substance

Abandoned Material that is burnt or incinerated or disposed of

Accumulated speculatively (in the context of solid waste) Storage of a waste material in lieu of expeditious recycling

Acute toxicity A level of toxicity by which an effect or mortality will occur within hours/days which is no more than two weeks after a single or multiple brief acute exposures

Acid A substance which releases hydrogen ions in water

Action plan A detailed programme of implementation of an activity over a time frame

Actinide An element with an atomic number between 89 and 103 inclusive. All are radioactive

Activated carbon Highly absorbent carbon made up of charcoal by increasing active surface area which can readily adsorb molecules of other substance coming in contact with its surface. It is mainly used to remove contaminants in air or water

Activated sludge Bacteria-laden sludge generated due to an aerobic treatment of wastewater called activated sludge process

Activation It is a process of inducing radioactivity

Activation product A radionuclide produced by activation

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Active effect Adverse effect on a receptor organism with symptoms of severity coming rapidly to a crisis

Active extraction systems The controlled extraction of leachate or gas from a landfill

Active landfills Landfills that are accepting solid waste

Acute toxicity Toxic effects which can lead to rapid detrimental effects on biological systems

Adhesion Molecular attraction which holds the surfaces of materials made up of different molecules

Adsorption Attachment of molecules of a material to the surface of a solid

Aerobic A processes carried out in the presence of oxygen

Aerobic composting Composting carried out in aerobic condition

Aerobic decomposition Decomposition occurring in aerobic condition

Aerobic treatment Treatment carried out in aerobic condition

Affordability (in the context of solid waste) Ability to avail solid waste management services

Agricultural waste Waste from agricultural waste

Air classification Process in which an air stream is used to separate materials

Air injection system (in the context of landfill) Injection of air into virgin soil usually adjoining the landfill in order to protect areas adjacent to a landfill due to movement landfill gas

ALARA Acronym of the phrase "as low as reasonably achievable". This means that an exposure to sources of radioactivity should be kept as low as possible

Alpha particle A positively charged particle released by atoms undergoing radioactive decay

Anaerobic Processes carried out in the absence of oxygen

Anaerobic digestion Digestion carried out in anaerobic condition

Anaerobic decomposition Decomposition carried out in anaerobic condition

Annex 1 countries These are the industrialised countries which have carbon reduction targets to reach under the Kyoto protocol

Anthropogenic Anything resulting from human activity

Aquifer A geological formation, capable of yielding significant amount of groundwater to wells or springs

Artesian The occurrence of groundwater at a pressure greater than atmospheric pressure

Artificial recharge Increasing water in the groundwater by activities of man

Ash The non-combustible, solid by product in combustion process

Asphyxiant Chemical capable of deny oxygen to cells in the host organism, resulting in slowing or halting metabolism

Atmosphere The gaseous layer surrounding the Earth

Autoclaving Sterilisation by high-temperature, pressurised steam process

Avalanche Snow ice that slides down a mountainside due to natural/anthropogenic causes

Avoided cost of disposal The amount that would have been paid per unit quantity of waste for disposing of materials in a landfill

Back blading A levelling method wherein the cutting edge of a blade of earth moving equipment is drawn backwards over cover material or waste

Backfill The material used for refilling excavated portions of a repository during and after emplacement of waste

Bacteria A type of microscopic unicellular living organisms

Balefill Land filling by stacking bales of solid waste

Baling Compaction of solid waste into blocks to lessen volume

Ballistic separator A machine that segregates light fraction and large material

Bagasse Dry residue of sugar cane/beets after extraction of juice

Baghouse Air pollution abatement device made up of fabric bags

Baler Machine used to compress waste material into bundles

Basel convention An international treaty which established standards for international movement of hazardous waste

Beach litter The debris washed aground on coast line. It is also called tidewrack

Bearing capacity Maximum load a landfill can support per unit area without damage

Best practice Practice which is the most politically/technically/environmentally/economically sustainable and socially sensitive

Beta particle Electrons emitted by during the process of radioactive decay

Bio-accumulation Accumulation of certain chemical compounds in tissues of plants and animals

Biodegradable Capable of decomposing by microorganisms

Biodiversity Overall diversity of organisms in an ecosystem

Biogas Gas formed by digestion of organic materials

Biological treatment A treatment method that uses micro-organism to treat waste

Biomedical waste Infectious waste, generated during the activities like research, health care activities

Bio-reclamation Treating contaminated sites by increasing the microbial degradation of organic contaminants

Bio-remidiation Process in which organic waste in contaminated site or other media may be seeded with microorganisms to alter/destroy the waste

BOD (Biochemical Oxygen Demand) Parameter used to measure organic contamination in water. It is difference in oxygen concentration before and after certain period (usually three or five days)

Borehole A hole drilled in the ground

Bottom ash The ash that falls to the bottom of combustion chamber

Brownfields Abandoned or under-used industrial/commercial facilities where expansion/redevelopment is difficult due to contamination

BTEX An acronym for benzene, toluene, ethylbenzene and xylene. They are the chief volatile aromatic compounds present in fuel hydrocarbons

Budget Estimate of expenditure and revenue of an organisation

Bulk density The ratio of mass to volume

Bulky waste Large objects of solid waste which cannot be handled by usual municipal solid waste management practices

Bund (in the context of solid waste) An embankment used to prevent the movement of wastes

By-laws Subordinate legislation which is applicable and enforced within the legal borders

Canister A closed/sealed container for radioactive material

Calcinations Method for evaporating residues from of liquid wastes

Calorific Value The amount of heat produced during combustion of unit mass of substance

Cap (in the context of land fill) Impermeable material placed over the top of a closed landfill

Capacity building Improving managerial and technical skills of an organisation

Cask A vessel used for the transport and/or storage of radioactive materials

Capital cost Cost incurred towards investment

Carbon regeneration unit Treatment device used for regenerating spent activated carbon

Carcinogen An agent capable of causing cancer

Cardboard shredder Shredder that shreds cardboard into strips or a mesh pallet

Cathodic protection A form of corrosion protection used for underground storage tanks that use anodes or a direct current source to protect tank material by stopping the naturally occurring electrochemical process which will result in corrosion

Cells (in the context of land fill) A compartment within a landfill with defined boundaries

Centralised composting Centralised facility for the purpose of composting

Ceramic material A solid crystalline material, containing silicon dioxide and other inorganic oxides

Certification A statement of professional opinion based on knowledge and belief

CFCs Chloroflourocarbon compounds

Chemical treatment Treatment method that use chemicals

Chronic effect Adverse effect on a organism, with symptoms that occur slowly or recur frequently

Climatological disasters Events caused due to variation in climate

Clinical waste Waste from healthcare activities

Clean closure Means removal/treatment of contaminated soils/liquids/equipment/structures for a TSDF

Closed portion Portion of a facility closed in accordance with approved facility closure plan

Co-disposal The disposal of various types of wastes in one disposal facility

Cogeneration Production of electricity and heat from same fuel source

Collection/disposal interface The interface between disposal and collection of waste

Collection timing The time period when solid waste is collected from a collection point

Collection vehicle Vehicle used to collect waste

Commercial waste Solid waste generated from commercial activities

Commingled recyclables Mixture of many recyclable substances in one container

Commingled waste Mixture of all waste material in one container

Commissioning Starting an operation at a constructed facility

Communal collection : A system in which individuals bring waste to a predetermined collection point, from which it is collected for further processing and disposal

Community composting Composting activity by a community

Compaction Operation used to enhance the density of waste materials

Compactor Any power-driven mechanical equipment designed to compress and thereby reduce the volume of wastes

Compactor collection vehicle Large vehicle with an enclosed body having special power-driven equipment for loading, compressing, and distributing wastes within the body

Composition (in the context of solid waste) Quantitative depiction of the materials found in a waste stream

Compost Humus material produced from composting process

Composting Process of generating compost

Construction and demolition waste Waste generated from construction and demolition activities

Container Receptacle used for storage of substance

Contaminant Substance that has an adverse affect on water, air or soil

Contamination The degradation of environment quality due to anthropogenic activity to the extent that its usefulness is damaged

Contingency plan Document setting out an organized, planned, and coordinated course of action to be followed in case of a fire/explosion/release of hazardous waste constituents that could threaten human health/life or the environment

Conservation The management of natural resource to avoid exploitation/destruction

Consumer waste Materials discarded by a consumer

Cost-effective alternative An alternative method which is cheaper than other methods

Cost effectiveness analysis (CEA) Evaluation of costs of an activity

Coastline Place where land meets the ocean or sea

Covering Spreading of a layer of cover material on the top of the waste mass to minimise adverse effects on the environment

Cover material Material used for covering waste materials

Chronic toxicity Toxicity wherein adverse effects occur after a lengthy period of exposure of small quantities of the toxicant

Crusher Mechanical device used to break secondary materials such as glass bottles into smaller pieces

Cullet Clean, color-sorted, crushed glass which is used in manufacture of new glass products

Curb-side collection Method of collecting waste on curb side

Cyclone cyclone Large-scale closed circulation of air in the atmosphere above the South Pacific and Indian Oceans

Cyclone separator Particle separator that uses swirling airflow along with mass and density of the particles to separate particles in an air-particle stream

Daily cover (in the context of land fill) It is a cover of about 15 cm thick compacted layer of soil laid on top of solid waste cell at the end of every day. Sometimes 'artificial cover' such as foam, geotextiles and plastic sheets may be used in place of compacted soil

Decomposition The breakdown of complex organic material by micro organisms into simple elements or compounds

De-inking Process of removing ink from printed matter prior to recycling of paper

Densification Process of lowering density of waste

Densified refuse-derived fuel Fuel derived through compaction of solid waste to produce briquettes, pellets, or cubes

Digestion The biochemical degradation of organic material of solid waste, resulting in its partial liquefaction, gasification, and mineralisation

Direct charges (in the context of solid waste management) The charges levied on solid waste management service user

Disaster An extreme hazard event causing significant damage, disruption and casualties

Disaster management Systematic implementation of policies/strategies/measures to lessen the impacts of disasters

Disaster preparedness Preplanned activities to reduce the impact of disasters

Disaster recovery Actions taken after a disaster to restore the disaster stricken community

Disaster waste Waste generated due to a disaster

Disposables Consumer products and other items that are discarded after using once or a few times

Disposal (in the context of solid waste) The process of finally disposing a solid waste

Domestic waste Waste generated from household activities

Donor agency An international or national agency which donates funds for developmental activity

Double composite liner (in the context of land fill) A landfill liner system of artificial and natural soil liners to prevent groundwater contamination

Double-liner system System wherein two layers of either synthetic or natural liners are used in landfill to avoid groundwater contamination

Drop-off (in the context of solid waste Collection methods wherein individuals bring wastes to a designated collection site

Drop-off centre (in the context of solid waste) Centre used for dropping off waste

Drought Situation that arises when precipitation is drastically below normal levels

Dump A site used to dispose solid waste without environmental controls

Dustmen People engaged in collecting ash in England in the early 1800s and later engaged in collecting waste from London

Earthquake Shaking of the earth due to seismic activities

Earthworks Engineering activity connected with the movement of soils

Economic evaluation The evaluation of a proposed activity with respect to economic aspect

Ecosystem Interactive system of living things and their abiotic environment

Effectiveness The extent to which the objective has been met in practice

Efficiency Utilisation of resource in the best possible way by obtaining maximum possible output

Emission A material released in the air

Energy recovery (in the context of solid waste Obtaining energy from solid waste

End of life vehicle Vehicle which has comleted its useful period

Environment Abiotic and biotic components surrounding subject of interest

Environmental audit An assessment of a system for the compliance with respect practices, policies and controls

Environmental impact assessment (EIA) An analysis of proposed project with respect to impact on environment

Environmental monitoring A continuous or regular periodic sampling, analysis and direct measurement of environmental attributes

Erosion The removal of weathered land surfaces

E-Waste Waste electronic goods

Feasibility study Study of the practicability of a proposal

Fermentation Chemical reactions carried out by microbes

Ferrous metals Iron and its alloys

Filtration Separation of solid present in a fluid by mechanical straining

Final cover (in the context of landfill Cover provided with consolidated soil to landfill after filling with waste

Financial evaluation Evaluation of financial aspect of a project

Fly ash Non-combustible residual particles (ash) generated during combustion expelled along with flue gas

Fly-tipping Illegal deposit of waste onto land that does not have a permit to accept such waste)

Food waste Waste arising due to leftover of food

Freegans Scavenger living exclusively from food items discarded by super markets

Fuel cycle (in the context of nuclear energy) All operations connected with the production of nuclear energy

Gas control and recovery system It is a system of wells and trenches with permeable materials as well as perforated piping in landfill to collect gases for treatment or for use as an energy source

Gas migration Movement of gas from one area to another

Generation rate The quantity of waste that is generated over a period of time

Generator Any person or organisation that generates waste

Geo fence Virtual perimeter for a geographic area

Geo tag Process of adding geographical identification mechanism to various media like Small Message Service (SMS)

Global positioning system System which determine latitude and longitude of a point on the earth

Ghost nets Fishing nets left or lost in the sea/ocean

Green waste All types of organic yard and landscaping waste

Grinding (in the context of waste) Grinding of waste to reduce the size of waste components

Groundwater Water present in the pores of underground soil

Groundwater monitoring well A well drilled for monitoring groundwater quality and quanity

Gyres Circular ocean current

Half-life The period taken for the quantity of a specified material to decrease by half

Hammer-mill Machine that uses hammers to grind, crush, shred or chip, waste

Haul distance (in the context of solid waste The distance over which waste must be transported from last pick-up point or transfer station, to the disposal point

Hauler (in the context of solid waste) Company/person responsible for transporting waste

Hazardous waste Waste that possesses corrosivity, ignitability, toxicity or reactivity

Heavy metals Metallic elements having high atomic weights, (e.g., mercury, cadmium, chromium, arsenic, and lead)

High efficiency particulate air filter High efficiency filters used for removing particles from a gaseous stream

Household waste (Domestic Waste) Waste generated due to household activities

Ignitable Capable of burning

Immobilization Converting of waste into a waste form by means of solidification embedding or encapsulation

Impervious Material which does not allow other substance to penetrate through

Inactive landfill Landfills which have stopped accepting wastes

Incineration Waste destruction by controlled combustion at high temperatures

Industrial waste Waste generated during an industrial operation

Inert Chemicals that does not react with other substances

Infectious waste Waste with infectious characteristics

Institutional waste Waste from schools, prisons, hospitals, public buildings and universities

Integrated waste management It is a practise of using numerous waste management methods to manage and dispose of solid waste

International NGO An organisation with branches in many countries

In-vessel composting A type of composting process wherein the compost is continuously and mechanically mixed

Itinerant waste buyer A person who moves from place to place for buying (or exchanging some other item) reusable and recyclable waste products

Key stakeholders People, groups or institutions that influence a project/programme

Landfill fire Burning of waste in a landfill

Landfill gases They are gases generated from the degradation of the organic matter from landfill

Landfills Controlled, designed and managed waste disposal sites

Landraising Type of landfilling wherein waste is spread in horizontal layers

Leachate Wastewater that trickles in waste dumps or landfill

Leachate collection system An engineered system for collecting leachate

Leachate management Management of leachate, which includes monitoring, collection and disposal

Leachate treatment Treatment of leachate to safeguard environment

Lift The completed layer of waste in a cell of landfill

Liner A relatively impermeable layer of natural or artificial material designed to contain leachate within a landfill

Litter Windblown solid wastes which predominantly comprise light materials like plastics and papers

Macro-routing Creating collection routes by dividing a collection area into small areas

Magnetic separation A method of separation using magnets to separate ferrous objects from solid waste

Mandatory recycling Mandatory stipulated by law requiring consumers to segregate waste so that recyclable objects are recovered for recycling

Manual separation Separation of various components of waste manually

Marine debris Anthropogenic waste which is released deliberately or accidentally into the sea. It is also called as marine litter

Marine life The pollution by plastic debris

Marine litter See marine debris

Market wastes Waste generated in market place

Mass burn system A system wherein solid waste is burnt in a controlled system without prior segregation or processing

Material recovery Recovery of useful components like plastic, paper etc., for the purpose of recycle/reuse

Materials recovery facility (MRF) Facility that processes waste to recover useful material

Mechanical separation Separating waste into various components mechanically

Medical waste Waste generated during health care activities of human beings or animals

Metropolitan area A politically defined urban area set up for planning or administrative purposes which may contain several municipalities or cities

Micro-organism Organisms which can only be seen by a microscope

Monitoring A process of examination, sampling, analysing and recording over a span of time

Mud-larks People engaged in cleaning services of England in the 1800s

Municipal solid waste (MSW) Waste from households, commercial and business establishments, institutions generated in urban settlement

Municipal wastewater The spent or used water from any activity in urban settlement

Nano waste Waste with engineered nanoparticles, nanomaterials or by-products of a nanoscale

Natural liner A landfill liner made up of low-permeability soil

Night soil Human excreta

Nitrogenous wastes Animal/vegetable waste that contains significant quantity of nitrogen

Non-point source Pollution sources which cannot be traced back to single point (e.g. agriculture, forestry, urban, mining and city streets)

Open burning Burning of solid waste in open site without control on air pollution

Open dump Disposal of waste without environmental controls

Ocean dumping Deliberate discarding of wastes into sea

Operating cost It is day to day expenditure of an operation

Organic Any compound containing carbon and hydrogen

Orphan site Site contaminated by hazardous waste which is not capable of remediation and no responsible party can be identified

Packaging The material used in stores to carry or display a product

Packaging waste Packaging material disposed after the product in the package has been taken out for use

Particle-cut shredder Paper shredder that cut paper into tiny pieces

Passive venting A venting technique which makes use of pressure for migration of gases

Pathogenic Capable of causing disease

Pathogens Microbes capable of causing disease

Percolate To trickle through a permeable material

Permeability A measure of movement of fluids through the holes/voids of a solid

Permeable Having pores that permit fluids to pass through

Pest An organism that is injurious to environment or health

Pierce and tear shredder Shredder wherein rotating blades pierce and then tear the paper

Pilot programme A trial run of project/equipment/structure on a small scale

Point source A stationary single identifiable source of pollution

Pozzolan Pozzolan is a material that exhibits cementitious properties when combined with calium hydroxide

Pollution Presence of matter or energy in quantities that create undesired environmental effects

Porous Containing holes or voids

Phosphor Substance that exhibits the phenomenon of luminescence

Primary stakeholders People or institutions directly affected, by a proposed action or plan

Public cleansing services Services pertaining to waste collection

Public good Refers to commodities or services for the benefit of public

Public hearing A meeting of governmental officials with public to hear the concerns of an action or proposal

Putrescible Decomposable

Putrefaction Biodegradation in which foul smelling compounds are formed

Pyrolysis Combustion of an organic substance in the absence of oxygen to convert solid wastes to liquid and gaseous fuel

Quality assurance A system of procedures, audits, checks, and corrective actions to ensure quality

Reclamation Restoration of objects found in the waste to a useful purpose

Recyclables Waste fractions that still have usefulness and which could be recycled

Refuse Another word for municipal solid waste

Rejects Residual waste

Refuse-derived fuel (RDF) Fuel derived from solid waste

Refuse reclamation Converting solid waste into useful products

Remediation Removing or containing hazardous spills/materials from a site

Residential waste Waste produce from residents

Residual waste The discarded materials in the waste stream which are not recyclable or compostable

Residue Residual waste

Resource recovery The process of obtaining material or energy from waste

Reuse Using a waste material in its original form more than once

Salvage (in the context of waste management Controlled separation of reusable and recyclable materials

Sampling Collecting a small quantity of material out of a large quantity of material

Sanitary landfill A term for landfill used in the USA

Sanitation Residues Human excreta residues from latrins

Scrap Materials discarded from manufacturing process that may be suitable for reuse/recycle

Screen Device used for separating different sized material

Secondary collection The collection of waste from collective collection points to a recycling centre, transfer station, intermediate treatment facilities or disposal site

Secondary raw materials Materials that are reused as raw material in any manufacturing process

Secondary treatment The wastewater treatment which follows primary treatment

Seepage See leachate

Sewage sludge Sludge generated from sewage treatment facility

Sharps Sharp waste objects such as needles, syringes, broken glassware, etc

Shredder A mechanical device used for breaking large sized materials into smaller fragments by tearing and impact action

Siting Siting is the process of selecting a location for a facility

Sludge A semi-solid residue from water/wastewater treatment processes

Soil conditioner An organic material that helps to enhance quality of soil for agricultural purpose

Soil liner See liner

Solid waste Solid material which does not have immediate use for a generator

Solidification Conversion of gaseous and liquid materials into a solid waste form

Source reduction Reducing the quantity of waste

Source separation Segregating wastes into various components at the point of generation

Stakeholders People, groups or institutions with interests in a programme or project

Standards (in the context of pollution) Norms that impose limits on quantity of pollutants or emissions generated

Steering committee High-level committee to oversee a project

Sterilisation The killing of all living organisms in a given material

Storage Temporary holding of material

Storage containers Vessels used to contain material for storage

Strip-cut shredder Paper shredder which uses rotating knives for generating narrow strips

Syngas It is the name given to a mixture of gases synthesized from waste materials

Tailings Residues from ore processing

Temporary storage (in the context of solid waste) Temporary holding of waste for further collection, transportation, treatment and disposal

Tertiary collection system Waste collection system wherein waste is collected after secondary collection system from recycling facilities and transfer stations and hauled to treatment facilities and/or disposal points

Thermal treatment Use of elevated temperatures to treat waste

Tidewrack See Beach litter

Tipping fee A fee for unloading waste at transfer station, a landfill or recycling facility

Tipping floor Unloading place for vehicles that are delivering waste to a waste treatment facility or transfer station

Topography The physical features of a surface of ground

Toshers People engaged in cleaning sewers of England in 1800

Toxic Poisonous

Transfer (in the context of solid waste) The movement of waste between various stages in the collection, handling and transportation process

Transfer point A place designed for transfer waste to larger vehicles from collection vehicles for transport to transfer station, recycling centre and/or disposal sites

Transfer station A facility in which solid waste from collection vehicles is transferred to larger trucks for further long distance transportation to final disposal

Transportation The physical process of moving material/passengers/animals

Treks Stretch between places covered by walk

Trek stalls Shops on trecks

Trench method (in the context of landfill) A method in which solid waste is disposed in trenches of a landfill

Urban agglomeration Heavily populated surroundings around a city

User charges Charges paid by the users for a service

Valorization A process of extracting a value-added stream in order to recover and conserve economic value

Vermi-compost Composting process that uses earthworms

Vertical Well (in the context of waste management) The drilled well for landfill gas collection in landfill

Virus A type of micro-organism

Vitrification The process of integrating materials into a glass or glass-like form

Void ratio (in the context of waste) Ratio between the voids and consolidated waste

Volume reduction Processing waste to decrease the volume by process such shredding, compacting, or incineration

Waste Unwanted materials remaining after an activity

Waste categories Group of wastes with similar properties

Waste collection The process of collecting wastes from point of generation

Waste collected The quantity of waste collected from collection points

Waste collector A person employed to collect waste

Waste dump Indiscriminate deposition of solid waste

Waste dealer Individual or organisation purchasing waste for recycling or reusing

Waste exchange Exchange of wastes which would benefit of both parties

Waste hauled The quantity of waste transported

Waste minimisation Measures that reduce the quantity of wastes generated during the process of generation of waste

Waste picker A person who selectively chooses out recyclable/reusable materials from waste

Waste picking A process of picking of recyclable/reusable materials from waste

Waste prevention Strategies or activities undertaken to reduce the quantity of waste. It is also referred as waste avoidance, waste minimization, pre-cycling

Waste-to-energy plant Burning of waste to heat or generate electrical energy

Waste recovery facility Facility employed for recovering

Waste treatment and disposal facility A facility meant for waste treatment and disposal

Waste types Types of waste like commercial waste, household waste, institutional waste, construction debris, sanitation residues, street sweepings and industrial waste

Wastewater water from community, home, farm, institution or industry

Wastewater treatment plant A facility for treating waste water to bring down concentration of pollutants to desired level

Wet/dry collection systems A collection system wherein wet and dry solid wastes are collected separately

Wet scrubber Air pollution control equipment use to scrub air pollutants by scrubbing fluids like waster, basic solution etc

Wheel cleansing Cleaning of dirt sticking to the wheels of vehicle

White goods Large household appliances like microwave oven, refrigerators, washing and/or machines stoves

Windrow Lengthy elongated pile of material

Windrow composting A method in which composting is done by placing piles of solid waste and turning it occasionally

Working group (in the context of solid waste management) Team responsible for preparing the strategic solid waste management plan

Yard waste (yard trimmings) Waste from garden composed of grass clippings, leaves, twigs, branches, etc

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