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

R. Chandrappa and D. B. Das, *Solid Waste Management*,
Environmental Science and Engineering, DOI: 10.1007/978-3-642-28681-0_9,

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.

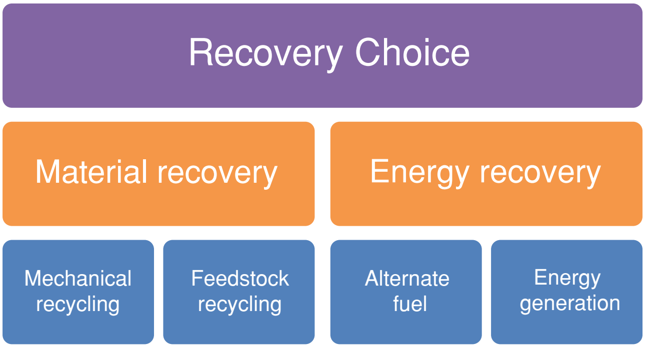

Fig. 9.10 Recovery choices for plastic waste

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) subbase 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,

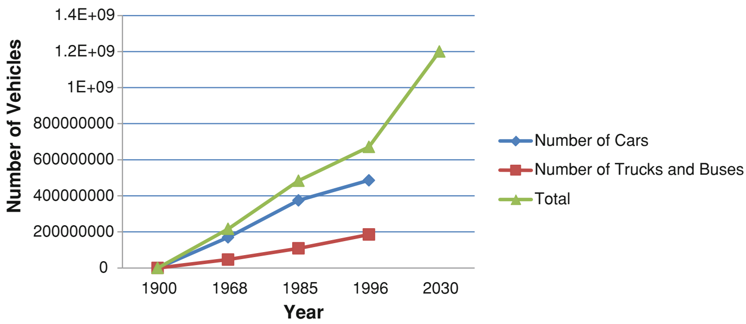

Fig. 9.13 Growth of number of vehicles in the world

(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 nonmetal 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 inter-connection 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.

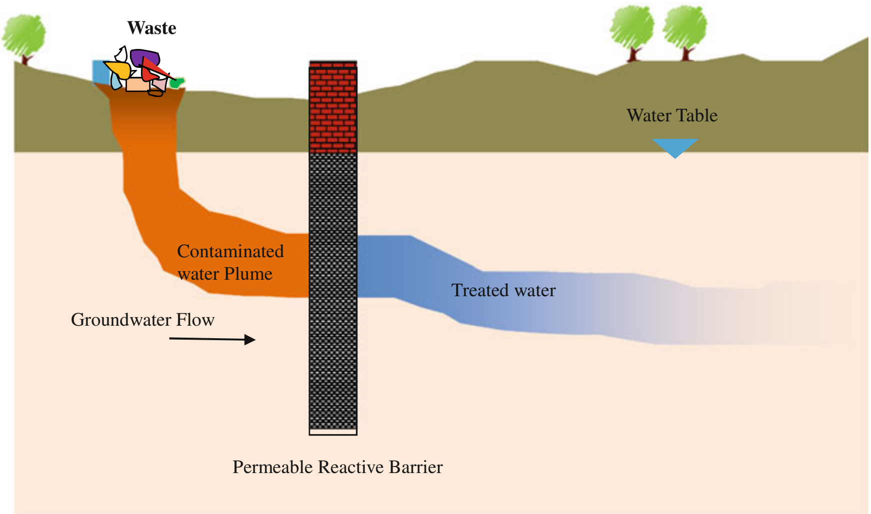

Fig. 9.18 Schematic diagram of permeable reactive barrier

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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