Chapter 15

Hazardous Waste

For centuries, chemical wastes have been the by-products of developing societies. Disposal sites were selected for convenience and placed with little or no attention to potential impacts on groundwater quality, runoff to streams and lakes, and skin contact as children played hide-and-seek in a forest of abandoned 55-gal drums. Engineering decisions here historically were made by default; lack of planning for handling or processing or disposal at the corporate or plant level necessitated "quick and dirty" decision by mid- and entry-level engineers at the end of production processes. These production engineers solved disposal problems by simply piling or dumping these waste products "out back."

Attitudes in the United States began to change in the 1960s, 1970s, and 1980s. Air, water, and land are now no longer viewed as commodities to be polluted with the problems of cleanup freely passed to neighboring towns or future generations. Governments have responded to public concerns with revised local zoning ordinances, updated public health laws, and new major Federal Clean Air and Clean Water Acts. In 1976, the Federal Resource Conservation and Recovery Act (RCRA) was enacted to give the U.S. Environmental Protection Agency (EPA) specific authority to regulate the generation, transportation, and disposal of dangerous and hazardous materials. The law was strengthened in 1984 with passage of the Hazardous and Solid Waste Amendments to RCRA. In the 1990s we found that engineering knowledge and expertise had not kept pace with this awakening to the necessity to manage hazardous wastes adequately. This chapter discusses the state of knowledge in the field of hazardous waste engineering, tracing the quantities of wastes generated in the nation from handling and processing options through transportation controls, to resource recovery, and ultimate disposal alternatives.

MAGNITUDE OF THE PROBLEM

Over the years, the term "hazardous" has evolved in a confusing setting as different groups advocate many criteria for classifying a waste as "hazardous." Within the federal government, different agencies use such descriptions as toxic, explosive, and radioactive to label a waste as hazardous. Different states have other classification systems, as did the National Academy of Sciences and the National Cancer Institute. These systems are displayed in Table 15-1. Selected classification criteria are described in more detail in Table 15-2.

Table 15-1. Historical Definitions of Hazardous Waste

	Definition Criteria											
	Toxicological	Flammability	Explosives	Corrosive	Reactivity	Oxidizing material	Radioactive	Irritant	Strong sanitizer	Bioconcentration	Carcinogenic, mutagenic	Quantity
15 U.S. Code, Section 1261 (commerce)	×	×		×			×	×	×			×
Code of Federal Regulations v. 16, Part 1500	×	×		×			×	×	×			×
Food, Drug and Cosmetic Act, 21 U.S. Code	×									×	×	×
Code of Federal Regulations v. 49. Parts 100–199 (transportation)	×	×	×	×		×	×	×				×
Code of Federal Regulations v. 40. Part 162 (pesticides)	×	×								×	×	
Code of Federal Regulations v. 40. Part 162 (ocean dumping)	×									×	×	×
NIOSH Toxic Substances List (occupational health)	×										×	
Drinking Water Standards, 42 U.S. Code	×						×			×	×	×
Federal Water Pollution Control Act, 42 U.S. Code	×									×	×	×
Clean Air Act Section 112, 42 U.S. Code	×				×		×				×	
California State List	×	×	×	×				×	×			
National Academy of Sciences	×	×			×							
Battelle Memorial Institute	×	×	×		×	×	×	×		×	×	
Department of Defense — Army	×											
Department of Defense — Navy	×	×	×	×	×	×	×					
National Cancer Institute	×										×	

Table 15-2. Classification Criteria for Hazardous Waste

Criterion	Description
Bioconcentration	The process by which living organisms concentrate an element or compound in levels in excess of the surrounding environment.
LD_{50} (lethal dose 50)	A calculated dose of a chemical substance that is expected to kill 50% of a population exposed through a route other than respiration (mg/kg of body weight).
LC_{50}	A calculated concentration of a chemical substance that, when following the respiratory route, will kill 50% of a population during a 4-h exposure period (ambient concentration in mg/L).
Phytotoxicity	The ability of a chemical substance to cause poisonous reactions in plants.

The federal government attempted to impose a nationwide classification system under the implementation of RCRA, in which a hazardous waste is defined by the degree of instability, corrosivity, reactivity, or toxicity. This definition includes acids, toxic chemicals, explosives, and other harmful or potentially harmful waste. In this chapter, this is the applicable definition of hazardous waste. Radioactive wastes are excluded (except in Department of Transportation regulations). Such wastes obviously are hazardous, but their generation, handling, processing, and disposal differ from chemically hazardous wastes. Moreover, all radioactive materials, as well as health protection from ionizing radiation, have been regulated by a separate and independent government agency: the Atomic Energy Commission from 1954 until 1974, and the Nuclear Regulatory Commission since 1974. The radioactive waste problem is addressed separately in Chap. 16.

Given this somewhat limited definition, more than 60 million metric tons, by wet weight, of hazardous waste are generated annually throughout the United States. More than 60% is generated by the chemical and allied products industry. The machinery, primary metals, paper, and glass products industries each generate between 3 and 10% of the nation's total. Approximately 60% of the hazardous waste is liquid or sludge. Major generating states, including New Jersey, Illinois, Ohio, California, Pennsylvania, Texas, New York, Michigan, Tennessee, and Indiana contribute more than 80% of the nation's total production of hazardous waste, and the waste's majority is disposed of on the generator's property.

A hasty reading of these hazardous waste facts points to several interesting, though shocking, conclusions. Most hazardous waste is generated and inadequately disposed of in the eastern portion of the country. In this region, the climate is wet with patterns of rainfall that permit infiltration or runoff to occur. Infiltration permits the transport of hazardous waste into groundwater supplies, and surface runoff leads to the contamination of streams and lakes. Moreover, most hazardous waste is generated and disposed of in areas where people rely on aquifers for drinking water. Major aquifers and well

withdrawals underlie areas where the wastes are generated. Thus, the hazardous waste problem is compounded by two considerations: the wastes are generated and disposed of in areas where it rains and in areas where people rely on aquifers for supplies of drinking water.

WASTE PROCESSING AND HANDLING

Waste processing and handling are key concerns as a hazardous waste begins its journey from the generator site to a secure long-term storage facility. Ideally, the waste can be stabilized, detoxified, or somehow rendered harmless in a treatment process similar to the following:

Chemical Stabilization/Fixation. In this process, chemicals are mixed with waste sludge, the mixture is pumped onto land, and solidification occurs in several days or weeks. The result is a chemical nest that entraps the waste, and pollutants such as heavy metals may be chemically bound in insoluble complexes. Asphalt-like compounds form "cages" around the waste molecules, while grout and cement form actual chemical bonds with the trapped substances. Chemical stabilization offers an alternative to digging up and moving large quantities of hazardous waste, and is particularly suitable for treating large volumes of dilute waste. Proponents of these processes have argued for building roadways, dams, and bridges with a selected cement as the fixing agent. The adequacy of the containment offered by these processes has not been documented, however, as long-term leaching and defixation potentials are not well understood.

Volume Reduction. Volume reduction is usually achieved by incineration, which takes advantage of the large organic fraction of waste being generated by many industries, but may lead to secondary problems for hazardous waste engineers: air emissions in the stack of the incinerator and ash production in the base of the incinerator. Both by-products of incineration must be addressed in terms of risk, as well as legal and economic constraints (as must all hazardous waste treatment, for that matter). Because incineration is often considered a very good method for the ultimate disposal of hazardous waste, we discuss it in some detail later in this chapter.

Waste Segregation. Before shipment to a processing or long-term storage facility, wastes are segregated by type and chemical characteristics. Similar wastes are grouped in a 55-gal drum or group of drums, segregating liquids such as acids from solids such as contaminated laboratory clothing and equipment. Waste segregation is generally practiced to prevent undesirable reactions at disposal sites and may lead to economics of scale in the design of detoxification or resource recovery facilities.

Detoxification. Many thermal, chemical, and biological processes are available to detoxify chemical wastes. Options include:

- neutralization
- ion exchange
- incineration
- pyrolysis

- aerated lagoons
- waste stabilization ponds

These techniques are specific; ion exchange obviously does not work for every chemical, and some forms of heat treatment may be prohibitively expensive for sludge that has a high water content.

Degradation. Methods that chemically degrade some hazardous wastes and render them less hazardous exist. Chemical degradation is a form of chemical detoxification. Waste-specific degradation processes include hydrolysis, which destroys organophosphorus and carbonate pesticides, and chemical dechlorination, which destroys some polychlorinated pesticides. Biological degradation generally involves incorporating the waste into the soil. Landfarming, as it has been termed, relies on healthy soil microorganisms to metabolize the waste components. Landfarming sites must be strictly controlled for possible water and air pollution that results from overactive or underactive organism populations.

Encapsulation. A wide range of material to encapsulate hazardous waste is available. Options include the basic 55-gal steel drum (the primary container for liquids), clay, plastics, and asphalt; these materials may also be implemented to solidify the waste. Several layers of different materials are often recommended for the outside of the drum, such as an inch or more of polyurethane foam to prevent corrosion.

TRANSPORTATION OF HAZARDOUS WASTES

Hazardous wastes are transported across the nation on trucks, rail flatcars, and barges. Truck transportation and particularly small-truck transportation is a highly visible and constant threat to public safety and the environment. There are four basic elements in the control strategy for the movement of hazardous waste from a generator — a strategy that forms the basis of U.S. Department of Transportation (USDOT) regulation of hazardous materials transportation as set forth in Vol. 49, Parts 170–180 of the Code of Federal Regulations.

Haulers. Major concerns over hazardous waste haulers include operator training, insurance coverage, and special registration of transport vehicles. Handling precautions include workers wearing gloves, face masks, and coveralls, as well as registration of handling equipment to control future use of the equipment and avoid situations in which hazardous waste trucks today are used to carry produce to market tomorrow. Schedules for relicensing haulers and checking equipment are part of an overall program for ensuring proper transport of hazardous wastes. The Chemical Manufacturer's Association and the USDOT operate a training program for operators of long-distance vehicles hauling hazardous materials.

Hazardous Waste Manifest. The concept of a cradle-to-grave tracking system has long been considered key to proper management of hazardous waste. This "bill of lading" or "trip ticket" ideally accompanies each barrel of waste and describes the content of each barrel to its recipient. Copies of the manifest are submitted to generators and state officials so all parties know that each waste has reached its desired

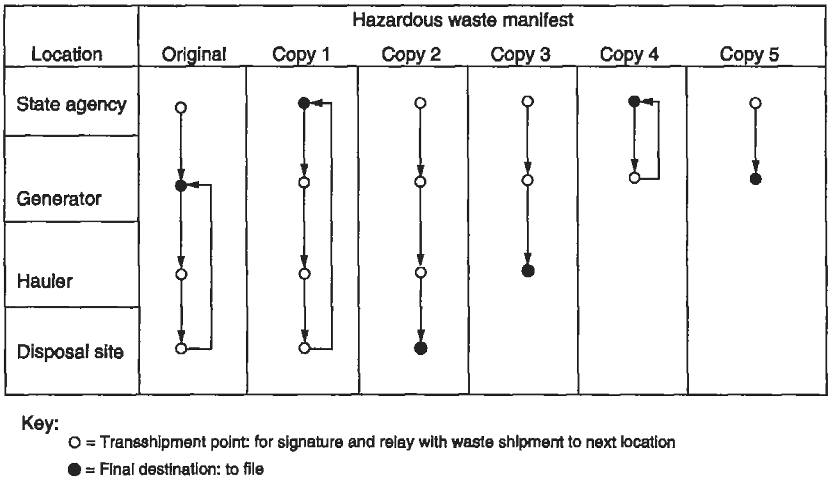

Figure 15-1. Possible routing of copies of a hazardous waste manifest.

destination in a timely manner. This system serves four major purposes: (1) it provides the government with a means of tracking waste within a given state and determining quantities, types, and locations where the waste originates and is ultimately disposed of; (2) it certifies that wastes being hauled are accurately described to the manager of the processing/disposing facility; (3) it provides information for recommended emergency response if a copy of the manifest is not returned to the generator; and (4) it provides a database for future planning within a state. Figure 15-1 illustrates one possible routing of copies of a selected manifest. In this example, the original manifest and five copies are passed from the state regulatory agency to the generator of the waste. Copies accompany each barrel of waste that leaves the generating site, and are signed and mailed to the respective locations to indicate the transfer of the waste from one location to another.

Packaging. Regulations of USDOT prescribe the design and construction of packages used to transport all hazardous materials, whether they are considered waste or usable materials. Corrosive material, flammable material, volatile material, material that, if released, would be toxic by inhalation, and any material that, if released during transportation, would pose a threat to human health and safety or to the environment must be packaged for transportation according to regulations.

Labeling and Placarding. Before a waste is transported from a generating site, each container is labeled and the transportation vehicle is placarded. Announcements that are appropriate include warnings for explosives, flammable liquids, corrosive material, strong oxidizers, compressed gases, and poisonous or toxic substances. Multiple labeling is desirable if, for example, a waste is both explosive and flammable. These labels and placards warn the general public of possible dangers and assist emergency response teams as they react in the event of a spill or accident along a transportation route.

Accident and Incident Reporting. Accidents involving hazardous wastes must be reported immediately to state regulatory agencies and local health officials. Accident reports that are submitted immediately and indicate the amount of materials released, the hazards of these materials, and the nature of the failure that caused the accident may be instrumental in containing the spilled waste and cleaning the site. For example, if liquid waste can be contained, groundwater and surface water pollution may be avoided. USDOT maintains a database of hazardous materials accident and incident reports on the website of the Bureau of Transportation Statistics (www.bts.gov).

RECOVERY ALTERNATIVES

Recovery alternatives are based on the premise that one person's waste is another person's prize. What may be a worthless drum of electroplating sludge to the plating engineer may be a silver mine to an engineer skilled in metals recovery. In hazardous waste management, two types of systems exist for transferring this waste to a location where it is viewed as a resource: *hazardous waste materials transfers* and *hazardous waste information clearinghouses*. In practice, one organization may display characteristics of both of these pure systems.

The rationale behind both transfer mechanisms is illustrated in Fig. 15-2. An industrial process typically has three outputs: (1) a principal product, which is sold to a consumer; (2) a useful by-product available for sale to another industry; and (3) waste, historically destined for ultimate disposal. Waste transfers and clearinghouses act to minimize this flow of waste to a landfill or to ocean burial by directing it to a previously unidentified industry or firm that perceives the waste as a resource. As the regulatory and economic climate of the nation evolves, these perceptions may continue to change and more and more waste may be economically recovered.

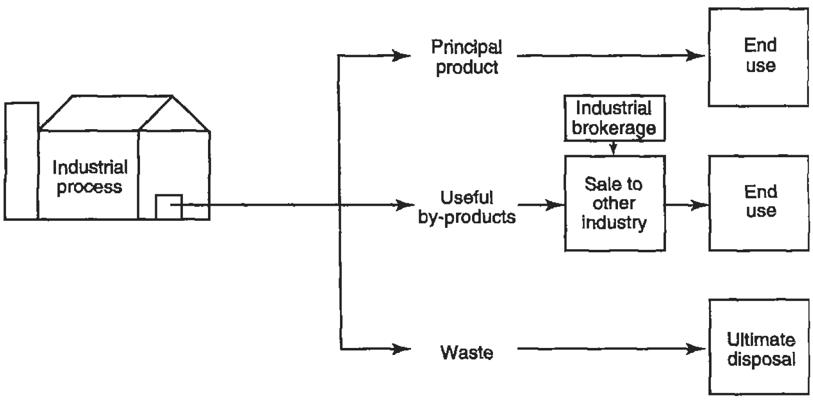

Figure 15-2. Rationale for hazardous waste clearinghouses and exchanges.

Information Clearinghouses

The pure clearinghouse has limited functions. These institutions offer a central point for collecting and displaying information about industrial wastes. Their goal is to introduce interested potential trading partners to each other through the use of anonymous advertisements and contacts. Clearinghouses generally do not seek customers, negotiate transfers, set prices, process materials, or provide legal advice to interested parties. One major function of a clearinghouse is to keep all data and transactions confidential so trade secrets are not compromised.

Clearinghouses are also generally subsidized by sponsors, either trade or governmental. Small clerical staffs are organized in a single office or offices spread throughout a region. Little capital is required to get these operations off the ground, and annual operation expenses are relatively low.

The value of clearinghouse operations should not be overemphasized. Often they are only able to operate in the short term; they evolve from an organization with many listings and active trading to a business with minimal activity as plant managers make their contacts directly with waste suppliers and short-circuit the system by eliminating the clearinghouse.

Materials Exchanges

In comparison with the clearinghouse concept, a pure materials exchange has many complex functions. A transfer agent within the exchange typically identifies generators of waste and potential users of the waste. The exchange will buy or accept waste, analyze its chemical and physical properties, identify buyers, reprocess the waste as needed, and sell it at a profit.

The success of an exchange depends on several factors. Initially, a highly competent technical staff is required to analyze waste flows, and design and prescribe methods for processing the waste into a marketable resource. The ability to diversify is critical to the success of an exchange. Its management must be able to identify local suppliers and buyers of their products. Additionally, an exchange may even enter the disposal business and incinerate or landfill waste.

Although exchanges have been attempted with some success in the United States, a longer track record exists in Europe. Belgium, Switzerland, Germany, most of the Scandinavian countries, and the United Kingdom all have experienced some success with exchanges. The general characteristics of European waste exchanges include:

- operation by the national industrial associations,
- services offered without charge,
- waste availability made known through published advertisements,
- advertisements discussing chemical and physical properties, as well as quantities, of waste, and
- advertisements coded to maintain confidentiality.

Five wastes are generally recognized as having transfer value: (1) wastes having a high concentration of metals, (2) solvents, (3) concentrated acids, (4) oils, and (5) combustibles for fuel. That is not to say these wastes are the only transferable items. Four-hundred tons per year of foundry slag containing 50 to 60% metallic Al, 150 m^3/yr of 90% methanol with trace mineral acids, and 4 tons of deep frozen cherries were transformed from waste to resource in one European exchange. One person's waste may truly be another person's valued resource.

HAZARDOUS WASTE MANAGEMENT FACILITIES

Siting Considerations

A wide range of factors must be considered in siting hazardous waste management facilities. Some of these are determined by law: for example, RCRA prohibits landfilling of flammable liquids. Socioeconomic factors are often the key to siting. Joseph Koppel (Koppel 1985) has coined the acronym LULU — locally undesirable land use — for a facility that no one wants nearby but that is going to be put somewhere. Certainly, hazardous waste facilities are LULUs.

In selecting a site, all of the relevant "-ologies" must be considered: hydrology, climatology, geology, and ecology, as well as current land use, environmental health, and transportation. EPA also requires risk analysis under regulations promulgated under RCRA (Chap. 3).

Hydrology. Hazardous waste landfills should be located well above historically high groundwater tables. Care should be taken to ensure that a location has no surface or subsurface connection, such as a crack in confining strata, between the site and a water course. Hydrologic considerations limit direct discharge of wastes into groundwater or surface water supplies.

Climatology. Hazardous waste management facilities should be located outside the paths of recurring severe storms. Hurricanes and tornadoes disrupt the integrity of landfills and incinerators, and cause immediate catastrophic effects on the surrounding environment and public health in the region of the facility. In addition, areas of high air pollution potential should be avoided in site selection processes. These areas include valleys where winds or inversions act to hold pollutants close to the surface of the earth, as well as areas on the windward side of mountain ranges, i.e., areas similar to the Los Angeles area where long-term inversions are prevalent.

Geology. A disposal or processing facility should be located only on stable geologic formations. Impervious rock, which is not littered with cracks and fissures, is an ideal final liner for hazardous waste landfills.

Ecology. The ecological balance must be considered as hazardous waste management facilities are located in a region. Ideal sites in this respect include areas of low fauna and flora density, and efforts should be made to avoid wilderness areas, wildlife refuges, and animal migration routes. Areas with unique plants and animals, especially endangered species and their habitat, should also be avoided.