CHAPTER 1

HAZARDOUS WASTE

If we are going to live so intimately with these chemicals—eating and drinking them, taking them into the very narrow of our bones—we had better know something about their nature and their power.

Rachel Carson, Silent Spring

What is hazardous waste? This chapter provides a working definition of hazardous waste and discusses its sources of generation and its classification. A review of the historical roots of hazardous waste issues explains why they became the dominant environmental program of the 1980s and will continue as a major program into the 21st Century. The two basic areas of hazardous waste management are presented: 1) management of currently generated waste and 2) remediation of sites contaminated by past practices. The chapter closes with a section on ethics, recognizing that technical decisions made in an arena of imperfect laws can affect the public.

1-1 WORKING DEFINITION

The term hazardous waste gained acceptance starting about 1970 with the first national study of the issue, and it became vogue in the mid-1970s with the development of legislative initiatives to regulate it. Long before then the wastes that we now know as "hazardous" were referred to by such terms as special industrial waste or chemical waste. This is still often the case in Europe. The term hazardous waste by itself is ambiguous. A feature of any regulatory program is to provide a legal definition to determine what is and what is not a hazardous waste. Developing a legal definition can take considerable effort with much disagreement. The U.S. Environmental Protection Agency (EPA) took nearly four years from the passage of the nation's first hazardous waste law in 1976 before promulgating regulations that defined hazardous waste. And
even then the definition used rather broad terms, included a myriad of exceptions, and has shown the periodic need for refinement. Some exceptions are based less on the waste’s inherent hazard than on its generator’s political influence.

Other nations have had similar experiences. Each has developed its own administrative definition for identifying and classifying hazardous waste to the particular level of detail necessary to support its legal procedures. These definitions lack scientific rigor. Each reflects the environmental, social, and political policies of a nation’s government, and hence approaches, like governments, differ from each other. A practitioner must understand the current legal definitions that apply to a waste; these are introduced in Sec. 2-2. However, this textbook avoids dedicating a number of pages to explain the complexities of a legal definition because a legal definition would periodically change, and today varies from nation to nation. Instead, this chapter presents a practical, working definition.

Developing a working definition first requires defining the term waste. A terse definition of waste was prepared in a joint international study as follows: “A waste is a moveable object which has no direct use and is discarded permanently.” This definition implies solid waste. In fact U.S. federal hazardous waste laws tend to have stemmed from solid waste programs, and the EPA regulates hazardous waste as a subset of solid waste.

The use of the solid waste nomenclature would suggest that the definition covers only solids, sludges, tars, and the like. However, many liquids are considered hazardous waste, typically because of their high strength or because they are a mixture of a hazardous waste with water. Further, many liquid wastes are containerized upon generation and transported as such, thereby making them solid-like. Thus defined, hazardous waste can include solids, sludges, liquids, and containerized gases. It is important to note that hazardous waste excludes that which is discharged directly into the air or water; these wastes are regulated under air and water laws that long predated hazardous waste laws.

It can be seen that the form of a waste is not important when defining whether it is hazardous. Instead, the most critical part of any definition is to include those terms describing the characteristics that cause a waste to be considered “hazardous” (i.e., posing a substantial present or potential danger to human health or the environment). The potential for toxicity, particularly carcinogenesis, has resulted in the greatest public concern and heads any list of characteristics. However, a waste can be considered hazardous if it exhibits any of a variety of other characteristics such as being ignitable, flammable, reactive, explosive, corrosive, radioactive, infectious, irritating, sensitizing, or bioaccumulative. This textbook covers all such waste with the exception of radioactive and infectious waste because these two types require management and technical approaches typically different from those required for other types of hazardous waste.

Therefore, the following working definition of hazardous waste, virtually as prepared under the United Nations Environment Programme auspices in December 1983, serves as a basis for this book:

Hazardous wastes mean wastes [solids, sludges, liquids, and containerized gases] other than radioactive [and infectious] wastes which, by reason of their chemical activity or
toxic, explosive, corrosive, or other characteristics, cause danger or likely will cause danger to health or the environment, whether alone or when coming into contact with other waste. . . . 2

1-2 HISTORICAL ROOTS

Around the beginning of the 1980s, hazardous waste became the leading environmental issue of our society. Now, in the 1990s, while scientific information shows some potentially devastating problems with global ecosystems, hazardous waste still continues to attract far more attention when measured by the amount of federal money spent for environmental programs. As another measure, hazardous waste accounted for about 50% of the $8.2 billion environmental consulting market in 1991 (see Fig. 1-1).

Why has it commanded such importance?

As discussed earlier, a waste may be hazardous for any of a number of reasons. Of these reasons, the potential for some wastes to cause a toxic reaction in humans is preeminent among public concern. It is this concern (if not fear) compounded by misperception, neglect, mistrust, and politics that explains why hazardous waste dominates other environmental issues.

The problem did not emerge overnight. Environmental contamination by toxic substances from waste or other sources has a long history. It seems that many wealthy Romans suffered from lead poisoning two millennia ago; possibly the decline of the Roman Empire was due, at least in part, to lead-induced psychoses among the emperors. However, it is the rapid pace of our technological developments, beginning with the Industrial Revolution, that forms the real roots of the problem as we know it today.

The advent of the Industrial Revolution spurred progress on many fronts. Advances in medical science and public health reduced the death rate, thereby dramatically increasing human population. Personal consumption also grew rapidly as expanding industrial production, resource extraction, and intensive agriculture supplied more goods. With these goods came toxic substances, sometimes as part of the goods themselves, that became residuals after use. Sometimes toxic substances were in the wastes generated when making the goods.

Until recently, government policies did not require appropriate precautions for waste, and few were taken. Simply getting rid of waste was the standard. Relying on

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**FIGURE 1-1**

Hazardous waste dominated the $8.2 billion environmental consulting market in 1991. 3
the seeming inexhaustibility of the environment was the method. Gradually, exposure to hazardous substances occurred outside the workplace via various environmental pathways. It started first with inorganic compounds such as lead and mercury, and expanded later, upon their introduction in the twentieth century, with synthetic organic compounds. Although technological progress has given us new products that raised our standard of living remarkably, it is the nature of technological development to outpace our knowledge of all that it brings and what that means. The failure in this instance is caused more by ignorance than negligence. The long-term toxic nature of hazardous substances and the inability of the environment to assimilate them completely have done the rest.

The environmental and human health consequences of the residuals and wastes of our technological society were not understood or even recognized initially; it took years or decades for chronic effects to manifest themselves, and those cases were obscured by the fact that everyone is exposed to a wide number of chemicals. This changed when developments in the sciences of epidemiology, toxicology, and analytical chemistry enabled researchers to begin to recognize some noteworthy associations that had been overlooked earlier in our longer-term relationship with toxic chemicals. The landmark cases start not with a hazardous waste but with the effect of DDT residuals on bird populations. Soon afterwards, with mercury poisoning of human populations in Japan and some episodes involving PCBs and dioxia, it became clear that humans were also at risk. Each episode received considerable press in a new and increasingly popular media form that came to be called environmental journalism. Each episode advanced public awareness, heightened public concern, and pushed ahead the environmental movement, eventually prompting the hazardous waste legislation that drives how waste is managed today.

1-3 LANDMARK EPISODES†

DDT

Pesticides have continued to be potentially sinister agents in the public eye ever since Rachel Carson’s publication of Silent Spring in 1962. Ms. Carson riveted world attention to the interconnected web of all life by recounting how DDT residues could be found in deep-sea squid, Antarctic penguins, and the fatty tissues of Homo sapiens. In aquatic birds, high levels of DDT were associated with lack of fertility. Later it would be found that DDT inhibits calcium deposition in avian ovaries, leading to egg shells that are too thin to withstand adult weight. In Homo sapiens it was not egg shell thinning that was worrisome, but an insidious disease—in laboratory animals DDT exposure was associated with an increased frequency of cancer, one of the first cases associating cancer with exposure to a toxic chemical.

†Section 1-3 was prepared by Bruce Molholm, Ph.D., ERM, Inc.
Mercury

Mercury has dramatically different toxicologic properties depending upon its chemical state. As a liquid metal, it was once used to cure constipation, apparently with few adverse side effects. On the other hand, mercury salts, which were used to form felt in the Dutch hat industry, led to the neurologic disorder renowned as being "mad as a hatter." Organic forms of mercury, such as methyl mercury, have proven to be even more pernicious, having caused hundreds of cases of paralysis and sensory loss along Minamata Bay in Japan. Inorganic mercury from a chemical plant became methylated in sediments and then bioaccumulated in shellfish. Because shellfish are the major protein source for much of the local population, this situation was an epidemic waiting to happen. Similar poisoning epidemics have occurred elsewhere (e.g., in Iraq and other countries where persons unknowingly ingested seed grain laced with an organomercury fungicide). However, it was the Minamata disaster and its graphic depiction through Katagiri's remarkable photographs in the late 1960s that heightened global awareness of industrial pollution.

PCBs

Like DDT, polychlorinated biphenyls (PCBs) were produced at about 100 million pounds per year during the 1960s and 1970s. However, unlike DDT, which is useful only as an insecticide, PCBs had multiple uses such as transformer coolant, plasticizer, and in the manufacturing of carbonless paper. Two cases of accidental contamination of rice cooking oil in Japan and Taiwan in the late 1960s and mid-1970s exposed thousands of Asians to high concentrations of PCBs. Miscarriages and birth defects erupted within the exposed populations. Although later it would be shown that these prenatal health problems resulted not from PCBs themselves but from polychlorinated dibenzofurans (PCDFs) that formed when heating the contaminated rice cooking oil, the riveting environmental journalism made the world population vividly aware of the adverse human effects of "PCB" exposure. About the same time in the United States, the contamination of Michigan cattle feed by polybrominated biphenyls (PBBs) not only caused widespread human exposures via milk and other dairy products, but also followed more complex pathways to reach humans. Afflicted cattle were rendered and then used to prepare chicken feed; thousands of human consumers were exposed to PBBs through eggs and egg products. One incident involved 24,000 crates of PBB-contaminated shortcakes which were confiscated in Alabama. PBBs were found in some Michigan mothers' breast milk.

Love Canal

For many, Love Canal will always be the symbol of environmental contamination by hazardous waste. It was this pivotal event that eventually resulted in the passage of the Superfund Act (Comprehensive Environmental Response, Compensation, and Liability Act) in 1980 by the U.S. Congress. Not useful as a canal, this channel was sealed off at the ends and used in the 1940s and 1950s by Hooker Chemical Co. and...
others as a hazardous waste disposal site. Later, Love Canal would be filled in and covered, and then sold to the Niagara Falls, New York, School District for $1.00. The company informed the school district that the site was used for the disposal of chemical wastes, warning against any excavation and underground construction. This information was added to the deed and copied into subsequent deeds when the school district sold parcels of the property.

The Niagara School District built an elementary school on the site that became quickly surrounded by hundreds of homes, many with young children. By the late 1970s a chemical odor was frequently discernible, especially in the basements of the homes, which, according to the local style, often contained the children’s bedrooms. People began experiencing chemically induced problems. Chemical analysis of samples showed various chemical substance at the disposal site, including dioxin.

A local reporter, Michael Brown of the Niagara Gazette, decided to follow up on the anecdotal reports of a few diseases among children that seemed to be linked to indoor fumes. Merely by walking around the neighborhood, he soon discovered more than 100 highly believable examples of chemically induced illness. Furthermore, in many basements he himself could smell the chemical fumes, sometimes to the point of nausea and tearing of his eyes. Brown’s Pulitzer Prize-winning expose catalyzed local politics and also reached the outside world. Soon, the local community, led by Lois Gibbs, a housewife with two afflicted children, was demanding federal relief. In one pivotal meeting, the Love Canal activists, discontented with perceived inaction on the part of EPA, locked up two officials overnight until they received assurance from Washington that action would be taken. Ultimately, New York State and the U.S. government (Federal Emergency Management Agency) purchased those homes in the vicinity of the canal. By this time drums were being discovered in many back yards and most homeowners were more than eager to move out (see Fig. 1-2).

EPA later declared Love Canal a Superfund site. Today the site is being remediated. In contrast with general perceptions, the contamination at the site was never proven to have posed the level of risk initially estimated.

FIGURE 1-2
Boarded homes adjacent to Love Canal.
Times Beach

Perhaps the next most publicized episode in America's awakening concern with hazardous waste occurred in Times Beach, Missouri. As with Love Canal, dioxin would become the major toxic chemical of concern. In the late 1960s and early 1970s, wastes were taken from chemical plants near St. Louis and diluted into used crankcase oil (a legal practice at the time) and spread on dirt roads and horse farms for dust control (again, a legal practice at the time). In the early 1970s dioxins were unknown. However, when waste oil was sprayed at a horse farm in May 1971, many animals died. Even after 6 inches of topsoil was removed from contaminated areas, animals continued to die. Chemical tests showed dioxia contamination up to 100 ppm at the village of Times Beach. With the Seveso, Italy chemical factory explosion in 1976, and the widespread toxic effects caused by the dioxin released by this explosion, dioxin (tetrachlorinated dibenzo(p)dioxin or TCDD) would arguably become recognized as the most toxic synthetic chemical yet discovered. The EPA eventually dealt with the Times Beach case by buying all properties in the community and permanently evacuating the residents.

1-4 REGULATORY INITIATIVES

As these and numerous other episodes evolved and received publicity, the public quickly became more aware of the dangers posed to health and the environment by hazardous substances when not managed properly. In response to acute public perceptions, possibly spurred by environmental journalism, the U.S. Congress along with state and local governments, as well as other national governments, enacted sweeping legislation on two fronts:

1. Management of currently generated hazardous waste, and
2. Remediation of contaminated sites.

These laws covered hazardous waste from a "cradle-to-grave" perspective. Prior to these legislative initiatives, economic considerations compelled most generators to dispose of their waste at a low, short-term cost with nominal regard given to the long-term impact. Although the actual risk did not equal the public's perceived risk, the regulatory pendulum had swung dramatically with this legislation.

Currently Generated Waste

In 1970, the U.S. Congress first addressed hazardous waste by including with a solid waste law of minor significance a requirement that the Department of Health, Education, and Welfare (a predecessor to the EPA) conduct a comprehensive investigation of the storage and disposal of hazardous waste. No comprehensive program for regulating hazardous waste existed then. The programs that regulated wastewater effluents and air emissions addressed hazardous waste only in a peripheral manner; the existing solid waste program was small and only addressed municipal waste.
The EPA completed its report to Congress in 1973 and found that "... the magnitude of the hazardous waste problem was larger than originally anticipated, and that current disposal practices are generally inadequate." The report cited key examples where indiscriminate disposal of hazardous waste had caused adverse public health impacts, including the hospitalization of several people in 1972 in Minnesota after drinking well water that had been contaminated with arsenic wastes. With the impetus of the findings of this report and subsequent hearings, Congress included in the Resource Conservation and Recovery Act (RCRA) of 1976 Subtitle C empowering federal regulation of hazardous waste for the first time. This was focused on the recovery and recycling of solid waste; however, Subtitle C instituted a program to define which wastes are considered hazardous. Further, it required generators of hazardous waste to track the transportation of waste from the point of generation to its final disposition, to operate treatment and disposal facilities in accordance with established standards, and to otherwise manage hazardous waste properly. Thus, in the United States, hazardous waste regulatory initiatives started as just one small part of a small solid waste program. In a matter of a few years it overshadowed EPA's air and water programs.

The United States was not alone. Other developed nations took initiatives to address hazardous waste at about the same time. For example, the United Kingdom passed its Poisonous Waste Act in 1972 after a highly publicized cyanide episode, and the Federal Republic of Germany amended its solid waste laws in 1976 to regulate industrial waste. As a sidenote, Germany avoided the use of the term "hazardous" because of the emotional controversy spurred by the term.

**Contaminated Sites**

In the late 1960s and early 1970s, analytical chemistry techniques advanced to a level of high resolution. When applied to the environmental field, these techniques allowed routine detection and measurement of contaminants at concentrations two or more orders of magnitude smaller than possible just a few years earlier. This new ability to detect compounds at the part per billion level or lower allowed the identification of the widespread presence of potentially toxic compounds in the environment.

Toxic contaminants, deriving from numerous human activities, were detected in the air, water, and land of practically any community. Toxic contamination was no longer considered just limited to isolated cases where the adverse consequences of exposure had manifested themselves. Unfortunately, the scientific knowledge of the toxic effects of exposure to multiple compounds at low concentrations over a long period of time was not well understood and had not kept pace with the ability to detect and measure their concentration. Without this knowledge, but with the media coverage of Love Canal and other early-discovered dump sites, the public's awareness of toxic contamination turned into alarm.

Although the toxic contamination of the environment has numerous sources, of which hazardous waste is just one, sites such as Love Canal where hazardous waste had been mismanaged prompted severe public reaction. Some of the sites contaminated by past practices were indiscriminate dumping grounds; others were bankrupt
and abandoned manufacturing plants (see Fig. 1-3). Many were former hazardous waste storage, treatment, or disposal facilities, such as Love Canal, that had been subsequently closed, if not abandoned, with minimal plans for further care. It was becoming clear in the late 1970s that potentially thousands of inactive hazardous waste sites existed throughout the nation. Whether these had caused an adverse health effect or had even resulted in exposure was not known; as best the public perceived them as "ticking time bombs."

Neither RCRA nor any other law provided the mechanisms to address inactive sites contaminated by past practices. The U.S. Congress changed that in 1980 with the passage of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or more commonly known as "Superfund." This program seeks to identify sites involving past releases of hazardous substances to the environment and to implement remedial actions deemed necessary at each site to protect health and the environment.

Foundation of a Regulatory Structure

The two hazardous waste laws (RCRA and CERCLA) were based on the legal concept that generators are liable for the long-term impact of their waste management practices, including their past practices. This contrasts remarkably with the traditional policy that made short-term costs virtually the only economic factor. The enactment and implementation of laws with this foundation have greatly changed the impetus for waste management. They have also fostered a futuristic perspective: most generators endeavor to minimize waste, and many manufacturers even consider the life cycle of their products (from research through manufacturing to use by the consumer and eventually ultimate disposition). The regulatory programs born from RCRA and CERCLA have gained much experience in the years since their enactment, giving considerable insight into particular problem areas that the laws were intended to address. The programs have not slackened—even under considerable scrutiny that claims that
they are overreactive, ponderous, costly, and time-consuming. Instead, the programs now carry even greater authority. The public’s interest and concern with hazardous waste remain strong.

It should be noted that the RCRA and CERCLA regulatory programs evolved and operated separately. There are perhaps as many uncommon characteristics as common ones between the two programs. Indeed, there are scientific differences: currently generated wastes (i.e., RCRA waste) are usually a residue of an industrial operation and tend to be more concentrated than when found in soils and ground water contaminated by past practices (i.e., CERCLA waste). Even so, the substances in the waste in either case remain the same, as do the inherent hazard they pose to health and the environment. This book approaches the two areas (RCRA and CERCLA) together. The same basic scientific and engineering concepts apply whether the substance is in a waste generated today or was released to the environment years ago in a spill, though the regulatory requirements frequently differ.

Public Perception of Risk

While hazardous waste does pose a real risk to human health and the environment, there is a debate about the magnitude of the risk, especially the risk compared with other sources of environmental contamination. Scientists assert that the public has exaggerated the real risks. In 1987, the EPA conducted a technical ranking of relative risks posed by 31 environmental threats and placed the health risk of hazardous waste sites below several other environmental problems. The relative rankings were based on the comparative evaluations and judgments of a technical panel of 75 experts. In contrast, a concurrent survey conducted by the EPA showed that the public perceived hazardous waste to represent a greater relative risk than most other environmental problems. This is shown in Table 1-1 comparing the EPA's experts’ rankings with public perceptions of selected environmental problem areas.

Why do public perceptions of the risk posed by hazardous waste not correlate with expert assessments? The public's perceptions are influenced by a number of non-

<table>
<thead>
<tr>
<th>Problem</th>
<th>EPA expert panel</th>
<th>Public opinion</th>
</tr>
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<tbody>
<tr>
<td>Hazardous waste sites</td>
<td>Low-medium</td>
<td>High</td>
</tr>
<tr>
<td>(active and inactive)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pesticide residue on foods</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Indoor air pollutants</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Consumer exposure to chemicals</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
technical factors such that a real risk is either perceived at a magnified level or simply is deemed unacceptable. Four of these factors are particularly applicable to hazardous waste generation or to a contaminated site, as follows:

- Involuntarily encountered—Because few people actually choose to live or work with hazardous waste, it is perceived as having been imposed upon a community or person. In contrast, smoking is known to be unhealthy, but it is a personal choice—it is voluntary—and thus those who smoke perceive the risk as acceptable.

- Having little apparent benefit—Few see any benefit in hazardous waste, ignoring that it results from some economic activity (e.g., manufacturing). In contrast, riding in an automobile poses greater risk but provides great direct benefit by getting one to where one wants or needs to go.

- Uncontrollable or controlled by others—The landmark contamination episodes such as Love Canal convinced many that hazardous waste is not controllable or at least those in control could not be trusted to manage it properly. In contrast, driving an automobile is controlled by the driver, and "Eighty-five percent of all drivers consider themselves better than average."13

- Having unknown but substantial consequence—It can be asserted that science has not developed the information to predict accurately the risk posed by hazardous waste. There is a virtual consensus, however, that birth defects and death are possibilities, however remote, from exposure to toxic substances in hazardous waste.

In aggregate, these four factors illustrate the great perceptual difference. The lack of agreement between public opinion and expert assessments does not suggest that either is wrong or even distorted. It is correctly pointed out that "... these are not distortions of risk; they are part of what we mean by the term."14 In the United States, regulatory programs are more closely aligned with public perception than with scientific assessments; that is, the political system bends to its constituency. Hence, the two federal hazardous waste regulatory programs (RCRA and CERCLA) continue to receive much of the nation's budget for environmental regulation, and together represent a massive and complex set of laws.

1-5 CLASSIFICATION

The basis for determining if a waste is hazardous typically occurs in either of two ways. First, laboratory tests may indicate that it exhibits one or more of the characteristics deemed to make a waste hazardous. Second, it may be on a list of specific wastes compiled by the government because it is known or suspected of having the potential to exhibit hazardous characteristics.

Testing

In the United States, any of the following four characteristics will make a waste hazardous:
• Corrosivity (waste that is highly acidic or alkaline);
• Ignitability (waste easily ignited and thus posing a fire hazard during routine management);
• Reactivity (waste capable of potentially harmful, sudden reactions such as explosions); and
• Toxicity (waste capable of releasing specified substances to water in significant concentrations).

The EPA has defined explicit laboratory procedures to analyze waste for these characteristics. The procedures include specific standards to determine whether the tested waste is hazardous (e.g., a corrosive waste is one with a pH ≤ 2 or ≥ 12.5).

Lists

The cornerstone of most regulatory programs is to itemize specific hazardous wastes into lists. Inclusion in such a list means that the waste is regulated as a hazardous waste. Some programs have prepared "exclusive" lists describing those wastes that are not hazardous, meaning anything not on the list is hazardous. This compares with the U.S. Food and Drug Administration's list of acceptable food additives. Such an approach to regulation was attempted in the United Kingdom but later abandoned.15

Most regulatory programs use an inclusive list. Federal regulations in the United States specify four inclusive lists, with some states adding others.16 Of the four, one lists hazardous waste from specific sources. These are wastes generated in specific processes unique to specific industrial groups. Wastes from these sources were tested nationally and found generally to exhibit at least one of the four hazardous characteristics. There are about 100 such wastes, referred to as "K"-wastes, and most made the list because of toxicity. Examples include vacuum stripper discharges from chlorodane production (pesticides industry), distillation bottoms from aniline production (organic chemicals industry), and spent pickling liquor from steel finishing operations (iron and steel industry). Many of the listed wastes from specific sources are sludges from air pollution control and wastewater treatment processes (e.g., sludge from the treatment of wastewater from wood preserving processes that use creosote and/or pentachlorophenol [wood preservation industry], emission control dust/sludge from certain steel production processes [iron and steel industry], and API separator sludge [petroleum refining industry]).

A variety of industries may use essentially the same standard operation as part of their particular manufacturing processes. If the waste generated by this standard operation typically is hazardous regardless of the industry, the waste is included on a second U.S. list of hazardous waste (i.e., non-specific sources), referred to as "F"-wastes. As examples, the manufacture of a great number of common products typically involves degreasing and electroplating operations. Certain spent halogenated solvents used in degreasing operations and spent cyanide-plating solutions from electroplating operations are F-wastes. Another example is the distillation residue and rea
cleanout waste from production of chlorinated aliphatic hydrocarbons. The wastes from non-specific sources ("F" list) tend to include many different chemical species.

The EPA has two other lists, referred to as "P"- and "U"-wastes, for particular commercial chemical products. These products are regulated as hazardous waste when discarded in an essentially pure form. This includes off-specification products, and container and spill residues.

Some nations have an inclusive listing of chemical substances, either specific or by classes, that indicate a hazard to human health or the environment. Such an example would be PCBs (polychlorinated biphenyls). These nations typically place a concentration limit on such constituents that, when exceeded, automatically classifies the waste as hazardous. The critical concentration limit may rely on leaching or volatility testing. Considering that there are a large number, possibly thousands, of chemical constituents that could render a waste hazardous, the implementation of such regulatory programs can be cumbersome.

**Other Classification Systems**

Broad definitions and inclusive lists are very important in the regulation of hazardous waste, particularly to ensure that a hazardous waste does not escape the umbrella of regulatory coverage. However, a regulatory classification system has a number of limitations. It tends to ignore relative differences in hazards among waste. All wastes, once deemed hazardous, are accorded the same regulatory coverage. A regulatory classification system does not facilitate definition of hazard nor is it appropriate for evaluating treatment methods.

Consequently, some scientists and officials have proposed alternatives for defining hazardous waste based upon a degree of hazard concept. This concept considers individual constituents, their concentration, and their mobility, together with a number of site-specific factors such as potential pathways for migration, exposure routes, dosages, and mitigation. Although this alternative has been proposed, its implementation is impractical.

Another limitation is that a regulatory classification system, because it is driven foremost by the hazard posed by a waste, is limited to identifying a waste's hazardous characteristics and perhaps its constituents; the classification system does not describe adequately (in most cases) the concentration of the constituents nor all important physical and chemical characteristics. Without this information it is impossible to assess the treatability of the waste, its potential for recycling, or its likely fate if released to the environment. An example is the waste coded as D006 in the EPA system. (A waste determined to be hazardous based on testing is given a code, starting with the letter D, to indicate which specific characteristics caused it to be hazardous. In this case, D006 is a waste having a characteristic of toxicity due to the presence of hexavalent chromium.) Such wastes are often generated as sludges or liquids during electroplating operations; however, they are also generated during dust collection or deburring in the fabricated metals industry. These two examples of chromium waste vary considerably in their physical and chemical characteristics as do their risks if released to the environment.
Example 1-1 Waste classification. A waste coded under the EPA classification system as D001 means the waste has been determined to have the characteristic of ignitability. In some states, this is the largest type of waste shipped off-site. What are some examples of wastes labelled as such?

Solution. A waste coded as D001 could be a spent but readily recoverable solvent, a combustible liquid suitable for energy recovery, a low-Btu paint sludge or paint filter suitable for incineration, or even a non-combustible sludge such as tank bottoms removed with the aid of gasoline. The potential treatability for each of these is significantly different.

An alternative to the regulatory classification system is to classify a waste according to the following hierarchy:

1. Form or phase distribution (e.g., liquid or solid);
2. Organic or inorganic;
3. Chemical class (e.g., solvents or heavy metals); and
4. Hazardous constituent as it affects treatability (e.g., hexavalent chrome).

This system is simple, yet effective for engineering purposes (e.g., grouping those wastes having similar physical and chemical characteristics and general treatment requirements). Table 1-2 shows the basic classes of an expandable system used in several statewide studies to define the need for new hazardous waste treatment and disposal facilities. The system is expandable.

Example 1-2 Waste categories. How could the major category “Inorganic Aqueous Waste” listed in Table 1-2 be expanded?

Solution. It could be split up among the following subcategories:

- Acid—inorganic acids; aqueous liquid with pH values of 2 or lower;
- Acid with metals—acidic wastes with metal contamination (e.g., ferric chloride solution and spent pickle liquor);
- Alkali—inorganic alkalis; aqueous liquids with pH of 12.5 or higher;
- Alkali with metals—alkali wastes with metal contaminants;
- Cyanide—spent cyanide solutions from plating, stripping, and cleaning; and
- Hexavalent-Chrome—aqueous liquids containing hexavalent chromium in excess of a specified limit.

1-6 GENERATION

Hazardous wastes can originate from a wide range of industrial, agricultural, commercial, and household activities. They are generated by manufacturers of many everyday products, by manufacturers of specialty articles, by both service and wholesale trade
<table>
<thead>
<tr>
<th>Major category</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
</table>
| Inorganic aqueous waste   | Liquid waste composed primarily of water but containing acids/alkalis and/or concentrated solutions of inorganic hazardous substances (e.g., heavy metals, cyanide). | — Spent sulfuric acid from galvanizing  
— Spent caustic baths from metal finishing  
— Spent ammonium electrolyte from manufacturing electronic components  
— Rinse water from electroplating  
— Spent concentrates from hydrometallurgy |
| Organic aqueous waste     | Liquid waste composed primarily of water but containing admixtures or dilute concentrations of organic hazardous substances (e.g., pesticides). | — Rinse water from pesticide containers  
— Wastings of chemical reactors and formulation tanks |
| Organic liquids           | Liquid waste containing admixtures or concentrated solutions of organic hazardous substances. | — Spent halogenated solvents from metal degreasing and dry cleaning  
— Distillation residues from production of chemical intermediates |
| Oils                      | Liquid wastes comprising primarily of petroleum-derived oils.                    | — Used lubricating oils from internal combustion engines  
— Used hydraulic and turbine oils from heavy equipment operations  
— Used cutting oils from machinery manufacture  
— Contaminated fuel oils |
| Inorganic sludges/solids  | Sludges, dusts, solids and other non-liquid waste containing inorganic hazardous substances. | — Wastewater treatment sludge from mercury cell process of chlorine production  
— Emission control dust from steel manufacture and smelters  
— Waste sand from coking operations  
— Lime sludge from coking operations  
— Dust from deburring of chromium parts in fabricated metal industry |
| Organic sludges/solids    | Tars, sludges, solids and other non-liquid waste containing organic hazardous substances. | — Sludges from painting operations  
— Tar residues from production of dyestuff intermediates  
— Spent filter cake from production of pharmaceuticals  
— Distillation bottom tars from production of phenols  
— Soil contaminated with spilled solvents  
— Slop oil emulsion solids |
companies, as well as universities, hospitals, government facilities, and households. After a waste is generated, the generator can either manage the waste on site or transport it off site for treatment, disposal, or recycling, typically to a commercial hazardous waste facility. Hazardous waste managed on the site where it is generated is termed on-site waste. Waste managed at a site other than where it is generated is termed off-site waste and requires, in the United States, the use of a document termed a manifest for tracking its transport on a “cradle-to-grave” basis (see Fig. 2-5).

National Picture of Waste Generation

In the United States, generators are required to submit biennial reports of the generation, management, and final disposition of hazardous waste. The most recently analyzed data are those for 1987. The data provide an interesting overview of the hazardous waste generation and management dynamic as follows:

- 17,677 large quantity generators (those generating at least 1000 kilograms of waste per month) filed a report for 1987.
- These establishments generated about 238 million tons of hazardous waste.
- More than 90% of all hazardous waste was categorized as hazardous wastewater (it was aqueous liquid waste). Most of the hazardous wastewater is regulated as a hazardous waste merely because it is corrosive (having a pH less than or equal to 2.0 or greater than or equal to 12.5). Typically, these wastes pose a low degree of hazard, and almost all of it is treated on-site, frequently by neutralization, and discharged to either a surface stream or a municipal sewer.
- Only 2% of the generators accounted for 98% of the waste. More specifically:
  - 5 largest generators: >57% of the waste
  - 50 largest generators: >90% of the waste
- About 70% of the generators produced less than 100 tons each in 1987, “cumulatively accounting for only 0.1% of the nationwide generation.” This excludes the even greater number of generators, referred to as small quantity generators, who are exempt from the biennial reporting requirements because they generate less than 1000 kilograms per month (about 13 tons per year).
- The nation’s hazardous waste was managed at 3,308 treatment, storage and disposal facilities. About half of these facilities had capability only for storage. A vast majority of the facilities were on-site facilities.
- Of the total quantity of hazardous waste, 13% was disposed of in deep underground injection wells (mostly hazardous wastewater), 1% in landfills, and 6.4% by incineration, with the remainder mostly discharged to sewers or water bodies after treatment.
- Only 3% of the generated hazardous waste was managed off-site, virtually all at commercial facilities. Assuming that all of the hazardous wastewater was managed on-site, the split for the non-wastewater wastes was 70% on-site management and 30% off-site (see Fig. 1-4).
• About 46% of the off-site quantities were transported to facilities in a state other than where the waste was generated.

The high volume of the hazardous wastewater category distorts the national picture. Most public concern is focused on the non-wastewater types of waste, particularly that portion shipped off-site to commercial facilities. These facilities typically accept waste from out-of-state generators. In response to the concerns of their citizens, some state governments have attempted to restrain the import of waste; however, the interstate commerce clause of the U.S. Constitution has prevented these actions.

Overview of Sources and Types
As part of an effort to determine the need for new off-site facilities, many state governments have analyzed in detail the waste that is generated within their borders and managed off-site. The data developed in these efforts provide a relatively accurate and detailed basis for examining waste generation patterns. Table 1-3 summarizes the specific industrial sources of waste manifested in two states with large amounts of hazardous waste generation. Table 1-4 examines the types of waste manifested in these same states in terms of the engineering classification system presented in Table 1-2, which proves to be a very suitable scheme for depicting the dynamic situation of hazardous waste generation.

The two tables demonstrate the complex aspects of hazardous waste generation even within two states that border one another. Motor oils and other oils are generated in both states. However, they are regulated as hazardous waste in New Jersey but were exempt from regulation in Pennsylvania at least for 1987. Hence, the quantities of oil wastes manifested in Pennsylvania are nil. Pennsylvania has a larger population and a larger industrial base than New Jersey and hence generates more non-oil hazardous waste. However, the types of waste generated and the sources of the waste vary considerably. New Jersey contains more
TABLE 1-3
Industrial sources of hazardous wastes generated and manifested in 1987 (percent of statewide total)

<table>
<thead>
<tr>
<th>Standard industrial classification code</th>
<th>Industry</th>
<th>New Jersey</th>
<th>Pennsylvania</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Textile mill products</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>24</td>
<td>Lumber and wood products</td>
<td>0.3</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>25</td>
<td>Furniture and fixtures</td>
<td>&lt;0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>26</td>
<td>Paper and allied products</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>27</td>
<td>Printing and publishing</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>28</td>
<td>Chemicals and allied products</td>
<td>18.3</td>
<td>15.0</td>
</tr>
<tr>
<td>29</td>
<td>Petroleum and refining</td>
<td>7.3</td>
<td>1.5</td>
</tr>
<tr>
<td>30</td>
<td>Rubber and miscellaneous products</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>31</td>
<td>Leather and leather goods</td>
<td>0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>32</td>
<td>Stone, clay, glass, and concrete</td>
<td>0.7</td>
<td>1.6</td>
</tr>
<tr>
<td>33</td>
<td>Primary metals</td>
<td>5.0</td>
<td>39.5</td>
</tr>
<tr>
<td>34</td>
<td>Fabricated metals</td>
<td>6.1</td>
<td>5.8</td>
</tr>
<tr>
<td>35</td>
<td>Machinery, except electrical</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>36</td>
<td>Electrical and electronic machinery</td>
<td>1.7</td>
<td>14.7</td>
</tr>
<tr>
<td>37</td>
<td>Transportation equipment</td>
<td>3.0</td>
<td>0.8</td>
</tr>
<tr>
<td>38</td>
<td>Instrumentation</td>
<td>0.9</td>
<td>2.7</td>
</tr>
<tr>
<td>39</td>
<td>Miscellaneous manufacturing</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>40-47</td>
<td>Transportation services</td>
<td>5.6</td>
<td>—</td>
</tr>
<tr>
<td>48</td>
<td>Communications</td>
<td>0.2</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>49</td>
<td>Electrical and gas services</td>
<td>1.8</td>
<td>0.2</td>
</tr>
<tr>
<td>50-59</td>
<td>Wholesale and retail trade</td>
<td>6.9</td>
<td>6.6</td>
</tr>
<tr>
<td>73</td>
<td>Business services</td>
<td>9.0</td>
<td>0.3</td>
</tr>
<tr>
<td>75</td>
<td>Miscellaneous repair services</td>
<td>12.8</td>
<td>7.9</td>
</tr>
<tr>
<td>—</td>
<td>Other/undetermined</td>
<td>16.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>

chemical plans and refineries. Thus, the chemical products group and the petroleum and refining group are the two manufacturing industries with the largest percentage of the state’s manifested waste (total of 23%). Pennsylvania, famous for its steel industry, has 40% of its manifested waste generated by the primary metals industry alone. The standard industrial classification (SIC) code 76 (miscellaneous repair services) includes commercial hazardous waste facilities, and Table 1-3 indicates that this group is the second largest source in New Jersey and fourth in Pennsylvania. The wastes manifested by this group are either treatment sludges being sent to other facilities for final disposal, or they are wastes that have been consolidated and reprocessed at transfer stations prior to treatment or disposal. The industrial categories of retail trade and business services in New Jersey may include tank cleaning and remediation services and are accounted for differently in Pennsylvania.

Different categories of waste generators produce different types of waste. The large organic chemical industry based in New Jersey results in a larger portion of the waste in that state being organic, whether liquid, sludge, or solid. The large primary metals industry in Pennsylvania results in a different situation. In Pennsylvania, nearly
<table>
<thead>
<tr>
<th></th>
<th>New Jersey</th>
<th>Pennsylvania</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aqueous liquids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosive with metals</td>
<td>11</td>
<td>179</td>
</tr>
<tr>
<td>Contains cyanide</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Contains hexavalent chrome</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
<td>Corrosive, not otherwise specified (NOS)</td>
<td>16</td>
<td>82</td>
</tr>
<tr>
<td>Inorganics, NOS</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Organics, NOS</td>
<td>46</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Aqueous liquids, NOS</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total aqueous liquids</strong></td>
<td>103</td>
<td>282</td>
</tr>
<tr>
<td><strong>Organic liquids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-chlorinated solvents</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>Halogenated solvents</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Solvents, NOS</td>
<td>32</td>
<td>7</td>
</tr>
<tr>
<td>Combustible, NOS</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>Contains PCBs</td>
<td>3</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Total organic liquids</strong></td>
<td>106</td>
<td>113</td>
</tr>
<tr>
<td><strong>Oils</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automotive oils</td>
<td>54</td>
<td>0</td>
</tr>
<tr>
<td>Industrial oils</td>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>Fuel oils</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>Oils, NOS</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total oils</strong></td>
<td>122</td>
<td>1</td>
</tr>
<tr>
<td><strong>Organic sludges and solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With organics</td>
<td>50</td>
<td>8</td>
</tr>
<tr>
<td>Paint residues</td>
<td>&lt;1</td>
<td>0</td>
</tr>
<tr>
<td>Oily residues</td>
<td>43</td>
<td>10</td>
</tr>
<tr>
<td>Combustible, NOS</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Sludges and solids, NOS</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total organic sludges and solids</strong></td>
<td>111</td>
<td>18</td>
</tr>
<tr>
<td><strong>Inorganic sludges and solids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With heavy metals</td>
<td>66</td>
<td>192</td>
</tr>
<tr>
<td>Corrosive, NOS</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Reactive, NOS</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Toxic, NOS</td>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
<td>Sludges and solids, NOS</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total inorganic sludges and solids</strong></td>
<td>77</td>
<td>195</td>
</tr>
<tr>
<td><strong>Others</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td>539</td>
<td>628</td>
</tr>
</tbody>
</table>

Half the wastes are aqueous liquids with most of the aqueous liquid being pickle liquor generated by the steel industry. Of the inorganic solid waste with metals, 44% in Pennsylvania comes from electric arc furnace dust.
Manufacturing Sources

What are the sources of hazardous waste? Most people associate the generation of hazardous waste with large chemical plants. While the chemical manufacturing industry represents a large source, Table 1-3 shows that other manufacturers (i.e., the chemical users) cumulatively produce far more. Primary manufacturers, those who prepare products from naturally occurring materials, may be thought of as the dominant source. Yet, waste generation extends beyond the primary and secondary manufacturing operations to include those companies that assemble and finish the final products demanded by our society for its style of living.

Virtually all manufacturing operations result in the generation of residuals because no production process can transform all input materials into products or services. Dependent upon economics and other factors, these “by-products” and “non-product output” can become wastes. Fashioning the steel, aluminum, plastic, and other components into automobiles and household items will generate abrasives and oils. Covering durable goods with attractive and protective finishes generates cyanides, solvents, concentrated acids, and paint sludges. Production of medicines yields organic solvents and other diverse residues, possibly containing toxic metals. Production of textiles generates heavy metal solutions, dyes, and solvents. The list of examples continues with electronic components, medical equipment, machinery, and publications.

Manufacturing waste may result from many different sources:

- Spent material—an input material that has been used and can no longer serve the purpose for which it was produced without reprocessing;
- By-products—material generated in the specific process of making a product and which has no use in its generated form without further processing;
- Treatment—sludges from treating wastewater, controlling air emissions, or even from treating or recovering other hazardous waste; and
- Commercial chemical products—an actual product that becomes a waste because of any of numerous reasons:
  1. Cleanup of process equipment, sometimes with chemical cleaners, such as alkalis, that are hazardous by themselves;
  2. Failure to meet manufacturer’s specifications because of production start-ups/shutdowns, upsets, breakdowns, or other factors;
  3. Accidental spills or leaks of raw material or product;
  4. Residue from containers used for raw material or product; and
  5. Outdated shelf life.

The generation of waste usually correlates with production and technology. For example, in a comprehensive study of hazardous waste generation in Illinois, the following observations were made:

- The manufacture of paint generated 4% to 6% of total production by weight as hazardous waste.
- The manufacture of steel generated 15 to 25 pounds of electric furnace dust per ton of steel produced.
- The manufacture of printing ink generated 1% of total production by weight as hazardous waste.

National data presented previously show that waste generation when including on-site waste is skewed toward the largest generators. This holds true even for manifested wastes. In New York State, an analysis showed that nearly 50% of the total quantity of manifested waste came from just 35 out of about 1,300 generators who manifested waste. In Missouri, only 28 generators in the entire state collectively accounted for 72% of the manifested waste. In New Jersey, 93% of the manifested waste came from 7% of the generators in 1990.

**Small Quantity Generators**

A wide range of waste is generated by service industries such as dry cleaners, automobile maintenance shops, and photographic film processors. Analytical laboratories at research and educational institutions and even the common household generate hazardous waste. The individual quantity of waste generated by such an operation is small. In fact, almost all generate less than 1000 kilograms/month, the level that exempts generators in the United States from most hazardous waste regulations. This exemption applies to both manufacturing sources and service industries, and such generators are referred to as small quantity generators.

Waste from a small generator, if mismanaged, has the same potential for harm as does fully regulated waste from larger sources. It is often disposed of in municipal landfills, in sanitary sewers, or in other ways not intended for hazardous waste disposal. It has even resulted in the death of two boys who were playing in an industrial trash storage bin and inhaled toluene generated from cleaning rollers for printing presses.

Surveys of small generators in Missouri and New York provide the comparisons shown in Table 1-5 to indicate the magnitude of the small generator issue. Most of the small quantity generator wastes are from automobile service establishments. In fact, 85% of the total waste in Missouri from small generators consisted of used motor oil and discarded lead-acid batteries, most of which were reclaimed. Other waste included spent solvents, acids/alkalis, and dry cleaning filtration residues. The small quantity generators in New York State and Missouri generated the waste quantities shown in Table 1-5.

**TABLE 1-5**

<table>
<thead>
<tr>
<th>Quantity of waste generated</th>
<th>Number of generators of hazardous waste in 1985</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New York State(^{39})</td>
</tr>
<tr>
<td>&gt; 1000 kg/mo</td>
<td>1300</td>
</tr>
<tr>
<td>100-1000 kg/mo</td>
<td>10,000</td>
</tr>
<tr>
<td>&lt; 100 kg/mo</td>
<td>27,000</td>
</tr>
</tbody>
</table>
cumulative quantity of hazardous waste from small generators can amount to more than 10% of the total quantity generated in a state, if not greater than 20%, as shown in Fig. 1-5.

### Household Hazardous Waste

The sources of hazardous waste extend even to the common household. A wide range of household products, when discarded, have the characteristics of hazardous waste. Pesticides, paint products, household cleaners, hobby chemicals, and automotive products frequently contain hazardous substances. Federal law specifically exempts household hazardous waste from regulation. Nevertheless, some local and state governments have implemented programs to educate the public about household hazardous waste and to operate waste collection programs. Data from various studies suggest that household hazardous waste collectively amounts to a significant quantity, perhaps as much as the cumulative amount from small generators.

### 1-7 CONTAMINATED SITES

The preceding sections have dealt with that hazardous waste currently being generated. The management of this waste is now subject to extensive regulation; however, such was not always the case. In the past, much waste was dumped indiscriminately or disposed of in inadequate facilities. These problems went ignored, as did spills of product or leaks from tanks. These practices contaminated sites with hazardous
substances that can pose a threat to human populations. A typical scenario is that contaminants released from a site migrated into the subsurface where infiltrating rainfall, spilled solvents, or ground water gradually transported the contaminants to points of ground water use or surface discharge.

A great number of such sites exist in the United States. Many took decades to be created, and all have had years of neglect. Defining the problem, especially at sites with multiple contaminants or with a complex environmental setting, can take years and considerable effort before remediation can begin. Remediation can be even more demanding. In a survey of state governments, it was estimated that the average elapsed time per site for the investigation and construction of a remedy is 4.5 calendar years.\(^{55}\) Implementation of some remedies can take decades. Collectively, the remediation of contaminated sites dwarfs the management of currently generated hazardous waste on virtually whatever scale one would use.

The potential extent of the problem is illustrated with a few basic data. The Superfund law requires the EPA to identify contaminated sites and long-closed disposal sites, and to maintain a list (the National Priority List) of the sites deemed to represent the greatest potential threat. As of August, 1990, there were 1187 sites on this list, referred to as “Superfund” sites. The EPA calls its National Priority List on a continuing basis from a much larger list of suspected sites of contamination. This larger list is termed CERCLA Information Service (CERCLIS). The CERCLIS list started with a total of more than 10,000 sites. Because newly discovered sites are added to CERCLIS, it soon grew to 20,000 and was approaching 30,000 as of 1993.

Superfund is just one program for addressing site contamination. Other programs include:

- Sites remediated by private parties to avoid government-regulated programs;
- Sites remediated under state Superfund programs—many states have their own programs for sites not included on the National Priority List;
- Currently operating or closed hazardous waste treatment, storage, or disposal facilities regulated as a hazardous waste facility under RCRA—about 4600 such facilities exist (3000 active and 1600 closed) containing as many as 36,500 separate waste management units;\(^{54}\)
- Sites remediated under federal programs other than EPA’s—both the Department of Defense and the Department of Energy have massive programs for remediating their properties;
- Property transfer initiated remediation—the buyer of property may demand remediation of contamination; some states require this before the legal transfer can occur; and
- Leaking underground storage tanks—there are perhaps as many as one to two million underground storage tanks in the United States and a significant percentage have leaked some of their product. Because these sites represent loss of product and not mismanagement of waste, most are remediated under separate federal and state programs and as such typically are not included on CERCLIS.
TABLE 1-6
Potential number of contaminated sites in New Jersey\textsuperscript{26}

<table>
<thead>
<tr>
<th>Program</th>
<th>Estimated total number of sites/facilities</th>
<th>Potential number of sites/facilities requiring remediation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superfund's National Priority List</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Current privately funded sites</td>
<td>107</td>
<td>107</td>
</tr>
<tr>
<td>Current state-funded sites</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>Planted additions to the above programs CERCLIS</td>
<td>71</td>
<td>71</td>
</tr>
<tr>
<td>Hazardous waste treatment, storage, and disposal facilities</td>
<td>1239</td>
<td>265</td>
</tr>
<tr>
<td>Property transfer initiated remediation</td>
<td>685</td>
<td>607</td>
</tr>
<tr>
<td>Underground storage tanks</td>
<td>30,000</td>
<td>9900</td>
</tr>
</tbody>
</table>

The potential size of the total remediation effort is illustrated by the data in Table 1-6 developed by the New Jersey Department of Environmental Protection.

In 1991 a university study estimated the cost of remediating contaminated sites in the United States. The estimate covered all government programs as well as privately funded efforts. The remediation of nuclear weapons complexes was included. The study placed the total cost over the next 30 years at $750 billion. This figure was based on current policies and technologies.\textsuperscript{26}

The enormous cost of remediating sites raises an important point about the future extent of remediation programs. The question is not whether contaminated sites exist; literally tens of thousands do exist. What is questionable is the level of risk posed by the sites and the degree of remediation necessary to reduce risks to acceptable levels. There is not a consensus that these sites pose, relative to other environmental problems, a level of risk that warrants the amount of societal investment necessary for their remediation. A policy decision to accept a higher level of risk would probably have two effects: at first, it would accelerate the pace at which sites are remediated, and second, it would eventually result in slackening the program. Nevertheless, site remediation would probably still represent a major environmental program even if it were slackened considerably.

1-8 FUTURE ENDEAVORS

John Quarles, the EPA’s first general counsel, recently reviewed the nation’s hazardous waste management strategy.\textsuperscript{27} He observed that in 1970, when the nation’s first Earth Day signaled the arrival of the modern environmental movement, hazardous waste management was an almost totally neglected subject. This has changed remarkably. He
noted that the federal hazardous waste laws have "...come to dominate environmental legal practice." He goes on to say that "At the current pace Superfund cleanups will require thirty to fifty years at a minimum," and that "Superfund sites are only one part of a much broader national waste contamination problem."

Environmental management, of which hazardous waste management is just one segment, is progressing through a fundamental change as shown in Fig. 1-6. For example, the Environmental, Health, and Safety (EHS) function in most corporations was an isolated entity that primarily dealt with compliance with laws. Today this function typically reports directly to the CEO and is involved in all aspects of corporate activity.

Clearly, the management of hazardous waste represents a challenge and opportunity for the environmental engineering and science professions. While remediation of contaminated sites currently commands the most attention, the increasing costs of managing today's hazardous waste, in combination with the legal foundation that makes generators liable for contamination in the long term, even for past practices, has prompted a new way of managing hazardous waste. Great effort will be expended to reduce, at its source, the quantity of waste generated and its degree of hazard. Looking further ahead, attention should focus on product life cycle, a systematic approach for examining the environmental and health consequences of a product at each stage of its life cycle and addressing such consequences in an integrated, cross-functional decision-making process. This results in products that are environmentally sound. Example considerations at each stage are shown in Fig. 1-7. Indeed, hazardous waste management is creating great demand for specialized fields of study within and combining the areas of engineering, geology, chemistry, and biology.

1-9 TOWARDS AN ENVIRONMENTAL ETHIC

Why a section on ethics in a book on hazardous waste? The management of hazardous wastes is not simply a technical problem but is confounded by legal, social, political, and, yes, ethical considerations. Engineers and scientists formulate conclusions and make recommendations that can easily result in de facto decisions that affect society as a whole. Embracing ethical standards will ensure that the public trust is not betrayed.
It is not possible, in this brief section, to provide the tools necessary for resolving the types of ethical problems that tomorrow’s hazardous waste manager will confront. Rather, our objectives here are more modest: to impress upon the reader that such considerations are of paramount importance and to show that help is available.

**Ethical Theories**

But where is this help to come from? Philosophers have been studying ethical questions for centuries. While they may not provide simple answers to the type of complex questions likely to be encountered, they do provide help in how to think about ethical questions.

The question of what is and is not ethical is not easily answered. In everyday life, one follows a broad set of personal rules that may include “do not cause pain” and “do not lie.” Conflict among the rules may occur which raises an ethical test (e.g., what should an individual do when the only way to avoid causing pain to another is to lie?). How can an individual then do both—be honest and avoid causing pain?

In engineering, rules of conduct are presented as various codes of ethics covering professional practice. For example, the engineer is admonished to be truthful in all dealings with the public. A code will usually express that the engineer is to remain loyal to the client or employer. But what about the situation when the engineer is privy to confidential information about a client’s past hazardous waste disposal practices and is asked by a regulatory agency to reveal what he or she knows. How does an individual remain loyal and retain integrity?

The answers to dilemmas such as these have been debated for more than two millennia, without definitive resolution. The search for the solutions to these questions has led to the development of a number of theories of ethics, most of them based on one of two general perspectives:

- Those focusing on the act, and
- Those focusing on the consequences of the act.
In the former, one is expected to follow the strictures of moral action and never to deviate from them. The consequences are not of any importance. If lying is not accepted, then one should never lie, regardless of the circumstance. Under this type of theory, an individual is acting ethically if he or she does not perform an act that is considered unethical.

Much of the ethical theory based on the importance of the act is based on the work of a German philosopher, Immanuel Kant (1724–1804). Perhaps his most important contribution was his Categorical Imperative:

There is . . . only a single categorical imperative and it is this: Act only on that maxim through which you can at the same time will that it should become a universal law.36

Under this theory, engineers would include in their set of ethical values only those rules that they are willing to observe and accept as inviolable (i.e., universal precepts that apply in all circumstances). If one can identify circumstances where a specific rule is inappropriate, the categorical imperative is not met and the rule is defective and lacking in ethical force.

The consequentialist ethical theory is credited in great part to the works of Jeremy Bentham (1748–1832) and John Stuart Mill (1806–1873). In this theory, sometimes termed utilitarianism, the consequences of the action are calculated in terms of how much pleasure and pain they produce for all people involved, and the ethical action is the one that has the greatest benefit for the greatest number of people. This is a very comfortable ethical system for engineers who are often placed in situations where it is necessary to calculate the benefits and costs of various projects, making it a “simple” matter to recommend the option having the highest benefit/cost ratio.

Unfortunately, the public does not always appreciate the beauty of utilitarian calculus. For an engineer, it is perfectly reasonable to calculate the public health effect of a hazardous waste incinerator, yielding an estimate that it has the potential to cause one excess case of cancer in a population of one million over a seventy-year period. But is this “cost” acceptable? The public does not care about these numbers. It understands that there will be an additional case of cancer and thinks that this is not right. Who will be the one to bear the unfair burden of this facility? By the public’s reasoning, the very act of causing one person to get cancer is not ethical, regardless of what the engineers think.

Such a divergence of ethical thinking is very difficult for many engineers and scientists to understand, and they will often attribute the reaction of the public to “technical illiteracy.” It is not technical illiteracy that is the problem, but a divergence of value systems. The question is how to make decisions where values conflict. Perhaps some resolution can be found in Hans Jonas’s The Imperative of Responsibility. He suggests that our first duty as citizens in a technological society is to visualize the long-range effects of technology, and this is followed by a second duty: “Summoning up a feeling appropriate to what has been visualized.”39 These are critical elements in what Jonas calls an “Ethic of the Future.”
Environmental Ethics

The previous discussion of ethical considerations addresses our behavior toward other persons, both individually and collectively as a society. But what is environmental ethics? In 1949, Aldo Leopold provided an exposition of environmental ethics in an essay termed "The Land Ethic." In commenting on the conservation attempts in Wisconsin, he bemoaned the fact that conservation decisions were being based solely on the economic value of the species in question:

One basic weakness is a conservation system based wholly on economic value. Wildflowers and songbirds are examples. Of the 22,000 higher plants and animals native to Wisconsin, it is doubtful whether more than 5 percent can be sold, fed, eaten or otherwise put to economic use. Yet these creatures are members of the biotic community, and if (as I believe) its stability depends on its integrity, they are entitled to continuance.40

Is it sufficient to treat the impact on the environment as essentially value free, unless that impact noticeably affects people? Gunn and Vesilind41 have termed this approach speciesism, a term akin to racism or sexism. This anthropocentric view of the world is probably the most prevalent in today's society, but attitudes towards the intrinsic value of nature are changing. At the time of the first Earth Day in 1970, it would have been impossible to imagine that the construction of a multi-million dollar dam would be held up over concern for an endangered species, a minnow named the snail darter.

Although there is a greater acceptance of the intrinsic value of nature today than in Leopold's time, we probably are still making decisions that Leopold would consider foolish and shortsighted. One reason for this can be found in an essay entitled "The Tragedy of the Commons" by Garrett Hardin.42 In it Hardin tells the story of a common pasture owned and used by farmers for grazing cattle. Because the commons is the property of all, there is nothing to prevent any farmer from adding an additional animal to the herd. All of the benefits (i.e., the value of an additional fattened calf) accrue to the farmer. The costs (the potential for overgrazing the commons) are not borne by the farmer alone but by all those using the commons. Each farmer being rational decides to maximize personal gain by maximizing the number of animals on the common. The eventual result of these individual decisions is a total destruction of the pasture through overgrazing. While Hardin directed his essay particularly at overpopulation and birth control, there is a clear message for the protection of all environmental resources. Protection is provided by laws; however, as shown earlier, law does not always suffice.

The Law

As will be seen in Chap. 2, much of the decision-making in the hazardous waste field is driven by ever more restrictive laws and regulations. If in fact these laws do represent a set of standards that our society has agreed upon, then why should we be concerned with ethical considerations? Isn't simply obeying the law enough?
The short answer is that the regulatory system presents a moving target. In addition, enforcement of all these laws is highly imperfect. For most corporations simply obeying the law is not enough. Informed corporations know that the laws will change and society will hold them to a higher standard. As discussed with site remediation, past practices done in compliance with laws in existence at the time can result in major future liabilities. Major environmental incidents, such as the Exxon Valdez oil spill in Alaska or the release of methyl isocyanate at the Union Carbide Plant in Bhopal, India, threatened the existence of these industrial giants. Smaller corporations know that such incidents could easily bankrupt them.

The current tendency is for corporations to move toward the use of corporate codes of conduct that require more than meeting the law. This is not done out of altruism, but rather due to a heightened environmental awareness on the part of corporate officials and heightened environmental expectation of the public. In short it is simply good business. An example of this trend is illustrated in Sec. 7-3 on Life Cycle Analysis. Using this method, corporations re-evaluate all of their activities from product research and raw materials purchase through the manufacturing and packaging of the final product to determine the impact on the environment.

Codes of Ethics

Engineers and scientists examine the health and environmental impacts of hazardous waste problems and generally have a good understanding of the degree to which mere compliance with the law will address the issues. Sophisticated clients will appreciate learning whether the law will suffice. What if the client decides to just comply when more seems proper? Help to answer this and earlier ethical questions can be found expressly in formal codes adopted by a number of engineering societies for governing the conduct of their members.

The Code of Ethics of Engineers adopted by the Accreditation Board for Engineering and Technology (ABET) is illustrated in Fig. 1-8. One characteristic of this and most other codes is the first canon: “To hold paramount the safety, health and welfare of the public.”

The National Society of Professional Engineers (NSPE) expands on this fundamental canon by noting in Part II of its code (Rules of Practice):

a. Engineers shall at all times recognize that their primary obligation is to protect the safety, health, property and welfare of the public. If their professional judgment is overruled under circumstances where the safety, health, property or welfare of the public are endangered, they shall notify their employer or client and such other authority as may be appropriate.43

The language in the ABET, NSPE, and other codes should make the engineers’ obligations to public health unequivocal. Ethics are not something that can be forced on a person. However, these codes represent the feelings of individuals who have long ago experienced ethical tests and decided that their profession and society would be better served by such actions.
CODE OF ETHICS OF ENGINEERS
THE FUNDAMENTAL PRINCIPLES
Engineers uphold and advance the integrity, honor and dignity of the engineering profession by:

I. using their knowledge and skills for the enhancement of human welfare;
II. being honest and impartial, and serving with fidelity the public, their employers and clients;
III. striving to increase the competence and prestige of the engineering profession; and
IV. supporting the professional and technical societies of their disciplines.

THE FUNDAMENTAL CANONS

1. Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties.
2. Engineers shall perform services only in the areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest.
5. Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
6. Engineers shall act in such a manner as to uphold and enhance the honor, integrity and dignity of the profession.
7. Engineers shall continue their professional development throughout their careers and shall provide opportunities for the professional development of those engineers under their supervision.

FIGURE 1-8
Engineering code of ethics.44

DISCUSSION TOPICS AND PROBLEMS

1-1. What are some of the problems encountered in finding a working definition for hazardous waste?
1-2. Is the form (e.g., solid, sludge, liquid, or gas) of a waste important in deciding if it is hazardous?
1-3. What is the purpose of grouping the different wastes according to characteristics (e.g., toxic) in classification lists? What are some of the problems with coding systems such as these?
1-4. Why is the generation of hazardous waste not only a result of large-scale industry? What are some other sources?
1-5. Why is it necessary to include a section on ethics in this book? What are some of the ethical considerations regarding decisions engineers have to make when working in the
hazardous waste management field? Give examples.
1.6. In manufacturing a generic product, name five potential sources of hazardous waste generation.
1.7. Contrast Hardings's *Tragedy of the Commons* with Leopold's *Land Ethic*. Give an example of how they apply to an environmental problem in the 1990s.
1.8. Why does the definition of hazardous waste specifically exclude radioactive waste?
1.9. Contrast the incident at Minamata Bay with that Love Canal, noting similarities and differences.
1.10. Describe the impact advances in analytical chemistry have had on the hazardous waste management field.
1.11. In the United States, generators are responsible for hazardous waste they create from "cradle to grave." Explain what is meant by this phrase.
1.12. What factors might explain the dramatic difference between the public's perception of the relative risk of hazardous waste sites and the opinions of an EPA expert panel (Table 1-1)?
1.13. What are the four characteristics that make a waste hazardous in the United States? Can you suggest other characteristics that might be appropriate to such a listing?
1.14. Explain why "degree of hazard" is not a factor in determining whether or not a waste is hazardous in the United States.
1.15. Review the hazardous waste facilities plan for your state and prepare a one-page summary of the most serious problems.
1.16. What are small quantity generators?
1.17. Review the summaries of generation in New Jersey and Pennsylvania (Tables 1-3 and 1-4). Explain the differences between these two contiguous states that cause the differences in waste generated.
1.18. Explain briefly the factors that might influence the amount of hazardous waste generated in a given year.
1.19. What is household hazardous waste?
1.20. What is the National Priorities List (NPL), and how does it differ from the CERCLIS List?
1.21. Explain what is meant by the Product Life Cycle approach to environmental management. Why have many corporations adopted this proactive approach?
1.22. Describe briefly the two general perspectives for dealing with ethical problems.
1.23. When it became known that a new process planned for a chemical plant was expected to produce a highly toxic waste, a plant environmental engineer wrote to the city newspaper expressing opposition to the action. Under what circumstances would the engineer's action be legal and/or ethical?

REFERENCES
2. Ibid.
11. Ibid.
12. Ibid.
14. Ibid.
31. Ibid.
32. Ibid.
44. Accreditation Board for Engineering and Technology, Code of Ethics for Engineers.

ADDITIONAL READING

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