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## **Chapter 4**

# **Current and Emerging Management and Disposal Technologies for Incinerable Hazardous Wastes**

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# Current and Emerging Management and Disposal Technologies for Incinerable Hazardous Wastes

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Incinerable wastes are currently managed by a broad array of methods; how extensively each method is used depends on innumerable economic, regulatory, and geographic factors. In addition, a wide range of new technologies for managing hazardous wastes is being developed, and many apply directly to incinerable wastes. This chapter first summarizes available data on the quantities of incinerable waste currently managed by particular methods and examines each method in more detail with respect to its potential for influencing the use of ocean incineration. Then the chapter briefly describes several new technologies with respect to their availability, capacity, and degree of applicability to incinerable wastes.

The discussion specifically excludes the large quantities of hazardous waste present in wastewaters that are directly and indirectly discharged into surface waters. Such disposal practices are regulated under the Clean Water Act and are specifically exempted from Resource Conservation and Recovery Act (RCRA) regulations applicable to hazardous waste. Moreover, only a small portion of incinerable liquid wastes is discharged into surface waters. Another OTA report (21) will examine these practices in detail.

## INCINERABLE WASTE QUANTITIES CURRENTLY MANAGED BY VARIOUS TREATMENT AND DISPOSAL METHODS

Several studies have estimated the quantities of hazardous waste managed through treatment, disposal, and recycling or recovery (6,18,24). However, only one study—by the Congressional Budget Office—was aggregated by waste type; this allowed separate estimates to be developed for the various categories of *incinerable* hazardous waste, which include waste oils, halogenated and non-halogenated solvents, and other organic liquids (ref. 18, and unpublished data).

The CBO estimates for the overall disposition of hazardous waste differed significantly in some cases from those of the Environmental Protection Agency (24).<sup>1</sup> The sources of data for both studies contain uncertainties and systematic errors which likely contribute to such differences. In addition, the universe of hazardous wastes considered in the

two studies differs significantly: CBO adopted a definition that is much broader than the RCRA definition used by EPA. Finally, CBO assumed full compliance with RCRA and Clean Water Act requirements in generating its estimates. Given these sources of uncertainty, the following discussion will provide a range of estimates, wherever possible, to provide a qualitative picture of current management of hazardous waste that could be incinerated.

Available data indicate that large quantities of waste that could be incinerated are currently being disposed of on land—in landfills, surface impoundments, or injection wells. Of liquids that could be incinerated at sea, CBO estimates that almost a third of oils and solvents and more than 80 percent of other organic liquids are disposed of on land. For incinerable sludges and solids, reliance on land disposal is even higher: CBO estimates that more than 80 percent of these wastes are land-disposed.

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<sup>1</sup>CBO acknowledged this discrepancy and discussed differences in the methodologies of the two studies in a paper (19) which accompanied its 1985 report (18).

The CBO data also indicate that most waste oils (about 60 percent) and significant quantities of waste solvents (5 to 10 percent) are burned in RCRA-exempt industrial boilers, currently under little or no regulation. These data are generally consistent with those from other sources (refs. 4 and 13; 50 FR 1684, Jan. 11, 1985).

The 1984 RCRA Amendments were designed to significantly restrict the use of these options for managing hazardous wastes, because of concerns about adverse impacts to human health and the environment. If the restrictions are implemented according to schedule, they are likely to significantly

increase the quantities of waste available for or directed to incineration.

CBO'S data and other data indicate that significant quantities of incinerable wastes, particularly liquids, are currently being recovered, reused, or recycled. These practices are likely to be increasingly used in the future. As shown in table 6 (see ch. 3), however, despite the anticipated levels of recovery, reuse, and recycling, it is likely that most incinerable hazardous wastes generated by 1990 will continue to require some form of treatment or disposal.

## CURRENT USE OF PARTICULAR TECHNOLOGIES FOR MANAGING INCINERABLE WASTES

Hazardous waste management technologies can be organized into a generally accepted hierarchy of methods ranging from least to most environmentally desirable or sound. This hierarchy can best be represented by a hazardous waste management "pyramid," with the following tiers:

- dispersion in the environment;
- isolation or containment;
- stabilization of waste through physical or chemical means;
- destruction or treatment of wastes to reduce toxicity;
- recovery of waste for recycling or reuse of materials or energy; and
- reduced generation of waste, with respect to both volume and toxicity.

A particular technology may actually contain elements from more than one tier in the hierarchy. For example, ocean incineration entails destruction of most of the waste, dispersion of a small amount of unburned wastes into the environment, and containment of any residuals by disposing of them in landfills. This section briefly discusses technologies (other than incineration) in light of the above hierarchy and indicates which technologies contain elements of more than one tier. Currently available incineration technologies are discussed in chapter 5.

### *Land Disposal*

Large quantities of incinerable hazardous wastes are now disposed of on land. Land disposal includes three primary methods: underground injection, landfilling, and surface impoundment. Although they are meant to isolate and contain wastes, all three methods have often resulted in dispersion of wastes, through leakage and migration of wastes from the disposal site. In some cases, wastes are stabilized prior to disposal in order to lessen the risk or degree of dispersion.

If implemented according to schedule and congressional intent, the 1984 RCRA Amendments' restrictions on land disposal would shift large quantities of hazardous waste, particularly incinerable liquids, away from land disposal. Almost all of the RCRA prohibitions, however, are contingent on the availability of alternative capacity for managing banned wastes. If alternatives are unavailable, temporary variances can be granted.

### **Underground Injection**

The injection of hazardous wastes into deep wells is the disposal technology used most often for such wastes. In 1983, an estimated 44 million metric tons (mmt) to 67 mmt, or one-sixth to one-quarter of

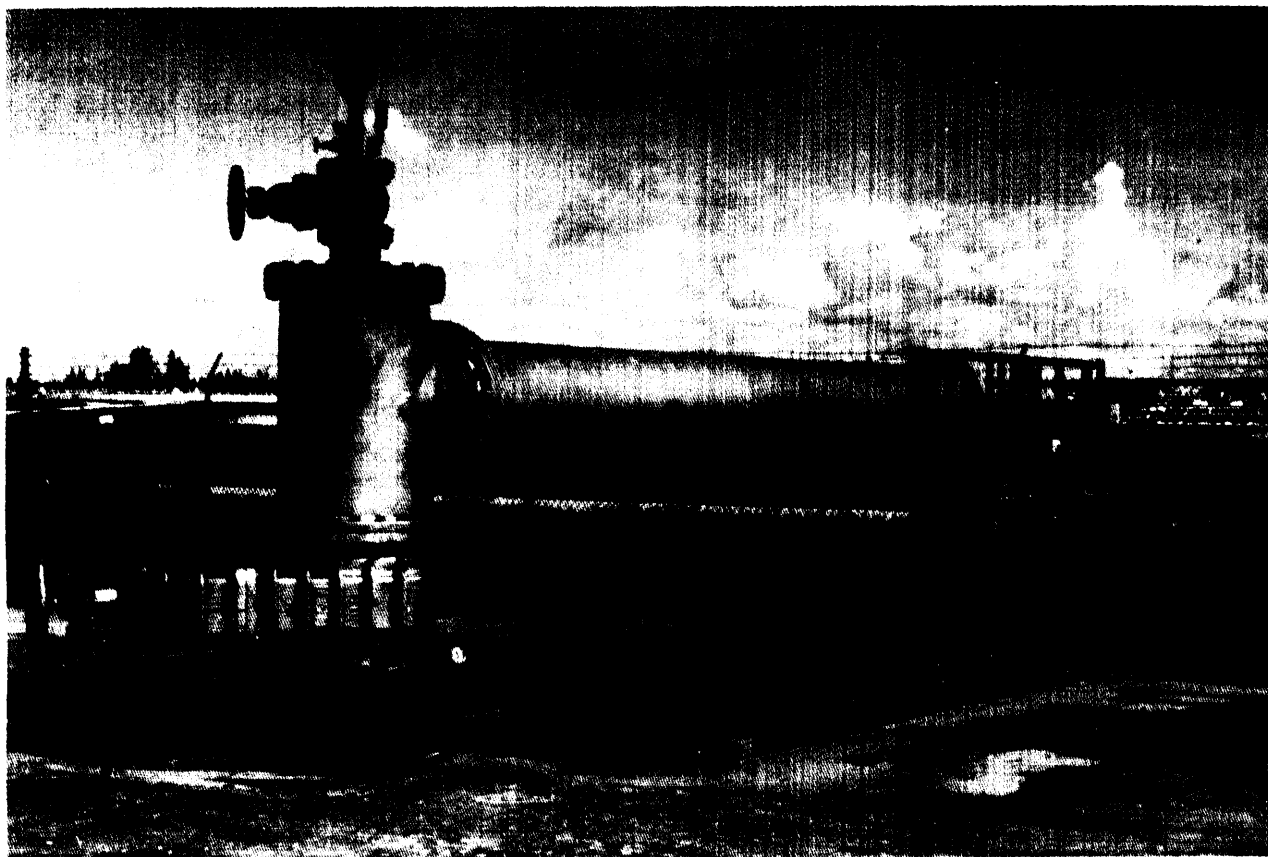


Photo credit: State of Florida Department of Environmental Regulation

Underground injection into deep wells is the technology most used to dispose of hazardous wastes.

all hazardous wastes generated, were disposed of by underground injection (ref. 18; EPA, cited in ref. 19). The 1984 RCRA amendments impose new requirements on this practice, although they are less stringent than those applicable to landfilling and surface impoundment. The schedule for banning the underground injection of hazardous waste is more gradual and the burden of proof of adverse impact may be somewhat more stringent.

#### Landfilling

CBO(18) estimated that over one-fifth of all hazardous wastes generated in 1983 was disposed of in landfills. Increasingly stringent RCRA requirements are raising costs, however, and are expected to lead to decreased usage. Minimum technology standards embodied in the 1984 RCRA Amendments require the use of double liners, leachate col-

lection systems, and groundwater monitoring capability. Landfilling of bulk liquid hazardous waste is already prohibited, and prohibitions on landfilling of other hazardous wastes are being decided on a legislatively mandated schedule.

#### Surface Impoundment

Surface impoundments, which include ponds, pits, and lagoons, are used to store and treat, as well as dispose of, many hazardous wastes. CBO (18) estimated that almost one-fifth (50 mmt) of all hazardous wastes generated in 1983 was placed in surface impoundments. Treatment processes used in surface impoundments include volatilization, evaporation, aerobic or anaerobic digestion, and coagulation and precipitation. Under the 1984 RCRA Amendments, the same minimum technol-

ogy standards applicable to landfills now apply to surface impoundments, although the immediate ban on bulk liquid hazardous waste does not apply.

### **Use of Incinerable Waste as Fuel**

A variety of technologies use incinerable waste as a fuel source. These technologies embody elements of the treatment/destruction and recovery tiers in the waste management hierarchy. In addition, disposal of residuals from such processes may involve isolation/containment or dispersion of wastes, as well.

Technologies employing incinerable waste as fuel compete directly with both land-based and ocean incineration. A regulatory distinction exists, however, between thermal technologies whose primary purpose is to use and capture the energy content of raw fuel or hazardous waste, and typical incineration technologies, which are designed primarily for the purpose of destroying wastes (46 FR 7666, Jan. 23, 1981).<sup>2</sup>

Various types of boilers and furnaces, both industrial and nonindustrial, employ incinerable waste as fuel to some extent. Nonindustrial boilers are used largely for space heating in apartments, office buildings, schools, and hospitals. Industrial boilers are used for space heating and steam production by utilities or other industrial facilities.

Industrial furnaces include cement and lime kilns, asphalt plants, and steel blast furnaces. Some of these technologies use the chlorine as well as the energy from hazardous wastes. For example, cement kilns use the acid gas formed from burning chlorinated wastes to reduce the alkalinity of the cement slag; the kiln itself acts essentially as a scrubber, and the quality of the cement product is actually improved in the process.

### **Profile of Existing Facilities Using Incinerable Waste as Fuel**

This section provides a profile of the number of these facilities and the extent of their use in burning hazardous wastes as fuel.

A very large number of industrial boilers and furnaces are used in the United States. EPA estimates

that about 43,000 industrial boilers and 600 industrial furnaces are currently in operation (4, 13). Of these, about 1,300 boilers and 10 to 20 furnaces burned some waste oil or hazardous waste-derived fuel in 1983 (25). EPA estimated that 3.4 to 5.4 mmt of hazardous waste and used oils are burned annually in industrial boilers (50 FR 1684, Jan. 11, 1985) and that about 0.35 mmt are burned annually in industrial furnaces (24). CBO (18) reported a much higher estimate of 9.5 mmt for industrial boilers *and* furnaces. In any case, significantly more hazardous waste is burned in industrial boilers and furnaces than is incinerated: 1.7 to 2.7 mmt (18,24).

While industrial furnaces and boilers appear to have enormous capacity for hazardous wastes, several factors limit their use. First, although these practices were exempted from RCRA regulations, the 1984 RCRA Amendments call for their regulation as hazardous waste facilities (see below). Second, these facilities have tended to burn only hazardous wastes that are relatively clean and have a high energy content. Attempts to significantly expand their use would involve wastes that are less attractive to facility operators, because they contain higher amounts of ash, water, or solids (13). Indeed, the reluctance of many operators to use such wastes for fuel is reflected in the small proportion of existing facilities that actually burn hazardous wastes (as indicated above).

A third factor limiting the use of these facilities for hazardous wastes is the relative lack of rigorous environmental testing or appropriate pollution control equipment. Very few industrial boilers are equipped with scrubbers (12, 13), so that wastes with significant chlorine or ash content could not be burned; moreover, the corrosivity of the resulting exhaust gases would damage the boilers.

A fourth factor limiting such use is the chlorine content of wastes. Wastes of intermediate chlorine content can be burned in cement kilns and other industrial furnaces, where corrosive gases are directly used in the production process. Burning of chlorinated wastes in kilns, however, tends to increase the release of particulate, necessitating that facilities be upgraded prior to such use (12). These and other factors limit the chlorine content of wastes that can be burned in such facilities.

<sup>2</sup>Incineration technologies are discussed in ch. 5.

In some States, industrial furnaces have experienced regulatory problems when burning hazardous wastes and have been forced to stop accepting certain or all such wastes. This has led to increasing quantities of waste being sent to commercial incinerators (2).

### Regulation

Some regulation of hazardous waste burning in boilers and furnaces has already occurred, and more is likely in the near future. Burning of hazardous waste in nonindustrial (particularly residential) devices is now strictly regulated and for the most part prohibited (50 FR 49164, Nov. 29, 1985). The 1984 RCRA Amendments prohibit burning of hazardous waste in cement kilns located in cities with populations exceeding 500,000 unless the facility complies with RCRA incineration standards (Section 204(b)(2)(c)).

For facilities producing fuels containing hazardous waste, notification and labeling requirements and product standards were also mandated and are currently being developed. In addition, exemptions for hazardous wastes or used oils burned as fuel are being removed, and new regulations governing their blending and burning are mandated. Finally, in 1986 EPA expects to issue permit standards that would extend the current performance standards and requirements applicable to land-based incinerators to all industrial boilers and furnaces (50 FR 49164, Nov. 29, 1985).

### ***Biological and Physical/Chemical Treatment<sup>3</sup>***

Many technologies for treating hazardous wastes are applicable to incinerable wastes. Biological methods include traditional aerobic and anaerobic digestion, in which naturally occurring bacteria are used to metabolize the organic constituents of the waste. Aerobic processes generally can be used only with relatively dilute wastestreams (liquids that contain low levels of solids), because high concentrations of waste components or metabolic products are often toxic to bacteria. Anaerobic procedures

are less sensitive, and have been used to digest sludges that contain significant amounts of solids.

Biologists have isolated naturally occurring bacteria that can degrade particular toxic or persistent chemical compounds (5,23). Particularly for specialized and highly problematic wastes such as PCBS, these and other emerging biological approaches may prove extremely useful and cost-effective.

Traditional physical/chemical treatment entails removing organic or metallic compounds from aqueous wastes—by using coagulant, absorbents such as activated carbon, or chemical reactions—and then destroying or disposing of the contaminated residues. Newer methods applicable to incinerable waste include several related technologies for dechlorination. Such processes chemically strip off chlorine atoms from highly chlorinated organic compounds, thereby greatly decreasing or eliminating their toxicity and persistence. Mobile units have been developed specifically to detoxify PC B-contaminated transformer fluids and PCB- or dioxin-contaminated soils.

### ***Waste Recovery and Recycling***

Current methods for recovering waste have been applied primarily to waste solvents and oils. Solvent recovery is a well established industry, which handles most of the waste solvents that are generated (18). Solvents are often sent offsite to be purified and returned to the generator for a fee. In other cases, the recoverer resells solvents to new customers.

Solvent recovery consists of several independent processes, which result in sequentially cleaner material. Some loss of quality relative to virgin materials accompanies all of these processes. Although this can lower the demand for recovered solvents, markets currently exist for both partially and fully recovered solvents. The intended use determines the extent of treatment; for example, use as fuel requires only minimal treatment, whereas reuse as solvent may require substantial treatment and expense.

The initial step in solvent recovery usually is to remove suspended impurities by filtration and centrifugation. Separation and removal of water, or

<sup>3</sup>Although incineration and other thermal processes are often classified as treatment technologies, this discussion is limited to nonthermal processes.

separation of different solvents present in a mixture, is accomplished through various forms of distillation. Each of these processes generates a residual, which must be disposed of or destroyed. For example, distillation generates various still wastes, which are candidates for incineration (on land or at sea).

**Waste oil recovery**, which is used to a much smaller extent than is solvent recovery, also entails several processes that produce sequentially cleaner material. Specifications based on intended reuse have been established, and they largely dictate the extent and nature of treatment. Reclaiming waste oil entails removing suspended solids, water, and degraded oil compounds. Reclaimed oils are blended or reformulated, resulting in products that can be resold for uses that do not require oil meeting the specifications for virgin material. Rerefining of reclaimed oil is accomplished through fractional distillation to generate a final product that approaches original specifications.

In addition to the new RCRA requirements that apply to the blending and burning of fuels containing hazardous waste, EPA has proposed listing used oil as a hazardous waste under RCRA (50 FR 49258, Nov. 29, 1985) and has proposed regulations governing recycled oil (50 FR 49212, Nov. 29, 1985). The regulations would ban the use of recycled oil for oiling roads and would extend to recycled oil those regulations that govern other recycled hazardous wastes.

A third method of waste recovery applicable to many types of waste is liquid extraction. This technique is especially useful for recovering a dissolved waste component that has economic value in its pure form. For example, phenol can be recovered in this manner from refinery and coke oven wastes.

A number of newer technologies, which have not been widely employed in the United States, can directly recover or use the chlorine released when chlorinated wastes are thermally destroyed. These

processes are discussed in the section on new and emerging technologies.

### **Waste Reduction**

Although the term waste reduction has a very broad meaning in common usage, in its most precise connotation it refers to technologies and processes that reduce the actual generation of waste (measured in terms of volume, or in terms of the toxicity or degree of hazard per unit volume). A technology like incineration reduces the toxicity and volume of waste, but a true waste reduction technology or process is used **before** the wastes are actually generated (i. e., in order to prevent their generation). The term, therefore, also excludes waste recovery technologies that reduce the quantity of waste requiring treatment or disposal but that act after the waste is generated.

Waste reduction technologies generally fall into two categories. First, process modifications reduce waste generation by, for example, internal recycling or more efficient use of feedstocks. These measures are 'typically process-specific, and the modifications are often driven by direct economic incentive. Even modifications that are not tied to the process itself have often been used to reduce waste (e. g., computer-based scheduling and inventory control in paint manufacturing) (1).

A second category of waste reduction technologies includes product or ingredient substitution, in which toxic or polluting materials are replaced by safer components. For example, water-based inks or adhesives can sometimes be substituted for those containing or made with organic solvents.

A full discussion of waste reduction far exceeds the scope of this study. For additional information, see references 3,9,14,15,16.4

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<sup>4</sup>Another ongoing OTA assessment (20) examines in detail the potential for industrial waste reduction.



## NEW AND EMERGING TECHNOLOGIES FOR INCINERABLE WASTES

A wide range of new technologies is being developed for the management of hazardous wastes. Many of these technologies, including methods for the recovery as well as detoxification (through treatment or destruction) of wastes, apply directly to incinerable wastes. A full analysis of the new technologies would exceed the scope of this assessment, but the topic has been examined in detail by others (7,8,11,22). This section briefly describes a few promising technologies and, where data are available, discusses their status, capacity, and degree of applicability to incinerable wastes.

### *Recovery Processes*

#### **Solvent Recovery—Thin Film Evaporation**

This technology, in which waste solvent is fractionated by evaporation from a thin film applied to a heated surface, provides an alternative to conventional solvent distillation. The technology's primary advantages over conventional distillation are a higher efficiency of recovery (greater than 95 percent), a smaller amount of residual material requiring disposal or destruction, and the ability to recover even highly viscous liquids.

A few commercial solvent recovery firms have recently installed thin film evaporators (1), but data on current or near-future capacity are not available.

#### **Advanced Oil Recovery Processes**

Application of advanced petroleum technology to waste oil has resulted in a number of new methods for removing contaminants and fractionating oil, thereby producing material that closely approximates original specifications. Several of these methods have recently been put into operation. The extent to which they would be applied to incinerable wastes would partly depend on oil prices and the relative cost of existing alternatives, including incineration.

#### **Chlorine Recovery Processes**

Several emerging technologies can use the chlorine that is released during the incineration of highly

chlorinated organic wastes (17). These technologies fall into two major classes. First, certain processes can recover chlorine liberated during incineration in the form of concentrated hydrochloric acid. These processes are generally applicable to a broad range of chlorinated organic wastes, but they have only been used on a small scale to date, probably in part because they are not competitive with other industrial sources of hydrochloric acid (10). Second, a group of related chlorination processes directly use liberated chlorine in additional chemical chlorination reactions. These technologies can be applied, for example, to the production of chlorinated hydrocarbons such as trichloroethylene, but the waste used in the process must be quite pure and homogeneous. To date, only wastes generated in the production of vinyl chloride and propylene oxide have been used successfully in chlorination recovery processes.

Both types of processes are limited by the market's capacity to absorb their products. In addition, the technologies have been used primarily in Europe and have not found significant application in the United States. Current costs are several times higher than those for ocean incineration of the same wastes, although the return on recovered materials can sometimes alter the ratio. From an environmental perspective, these recovery processes offer the advantage of occurring in relatively closed systems, thus greatly reducing the emissions associated with conventional incineration.

#### **Supercritical Fluid Extraction**

This process is an advanced form of liquid extraction, employing elevated temperature and pressure to extract particular organic compounds from waste mixtures. The process entails higher capital investment but lower operating costs than conventional distillation or solvent extraction. As with liquid extraction, supercritical fluid extraction is likely to be most useful for treating aqueous wastes containing valuable or highly toxic components. It may also be able to concentrate the organic portions of wastes in order to render their subsequent incineration more economical.

### ***Thermal Detoxification Processes<sup>5</sup>***

#### **High-Temperature Electric Reactor**

**This** technology is an advanced pyrolytic technique in which wastes are rapidly heated to extremely high temperatures (about 4,000° F) and destroyed. Its developer claims that the destruction efficiencies the reactor achieves are much higher than those required of, or achieved by, conventional incinerators. The reactor was initially developed to destroy organic contaminants in soils or carbon absorbents, but it has recently been used for liquid wastes, as well.

The reactor's throughput for solids is estimated to be as high or higher than that of conventional incineration, although for liquids the converse may be true. Commercialization is underway.

#### **Molten Salt**

This technology destroys organic wastes and removes inorganic residuals from combustion gases in a single step. Wastes are injected into a pool or bath of molten sodium carbonate or calcium carbonate maintained at a temperature of about 1,6500 F; the inorganic byproducts of combustion (containing phosphorus, sulfur, halogens, or metals) react with the carbonate component of the bath and are retained as inorganic salts. These products, as well as ash, must be periodically removed from the bath.

Molten salt baths are suitable for both liquid and solid wastes (including highly halogenated waste-streams) with low ash content. Throughput of a pilot-scale facility was estimated to be about 100 lbs/hr. No commercial units are currently employed, although they are available for purchase.

#### **Molten Glass**

A similar technology employing a molten glass bath maintained at about 2,200° F has also been developed. Inorganic components other than halogens are trapped and removed in a classified, and therefore highly stabilized, form. Scrubbers are necessary when this technology is used with halogenated wastes.

#### **Fluid Wall Reactor**

In this process, wastes pass through a porous carbon cylinder heated to about 2,200° F. A mobile unit has been developed for destroying dioxin-contaminated liquids and soils. Projected costs are comparable to those of offsite incineration.

#### **Plasma Arc**

Wastes are destroyed in this process by injection into an electrically superheated ionized gas (plasma). Temperatures employed are claimed to be extremely high: 10,000° F or more. An afterburner is usually attached to ensure complete destruction. The method has been used on PCBs and other highly chlorinated liquid wastes, and has demonstrated very high destruction efficiencies (higher than 99.9999 percent). A unit currently being demonstrated has a waste throughput of 600 lbs/hr. A commercial unit is expected to be available within a few years. The costs, which are projected to be 5 to 10 times higher than conventional incineration, would probably limit the technology's use to highly toxic liquids.

#### **Supercritical Water Reactor**

In this process, elevated temperature and pressure enhance the rate and efficiency of thermal oxidation of aqueous wastes. Inorganic constituents are either neutralized or precipitated, eliminating the need for scrubbers on systems fed with chlorinated wastes. Destruction efficiencies of demonstration units have been somewhat lower than those required of incinerators.

A reactor system now being developed would treat liquids and sludges containing high levels of inorganic and toxic constituents. The unit would be equipped with heat recovery capability as well. Throughput is expected to be between 1,000 and 2,000 gallons per day (300 to 600 lbs/hr). Commercialization is expected to occur within several years.

### ***Chemical Detoxification Processes***

As a general rule, incinerable wastes are not good candidates for chemical treatment. Particular wastes such as PCBs and dioxins, which have been the focus of considerable public attention, may be excep-

<sup>5</sup>This discussion is drawn primarily from refs. 1 and 8.

tions to this generalization. For more information about chemical detoxification processes, see ref. 1.

### Oxidative Ultraviolet Light Treatment

This process couples the oxidative capacity of ozone or hydrogen peroxide with the ability of high-energy ultraviolet light to break chemical bonds. Several techniques are being developed, but they are likely to be quite expensive, especially for waste with significant organic content, thus limiting their ability to compete with incineration. The techniques may, however, be useful for hard-to-treat wastes such as PC B- and dioxin-containing solids.

### Catalytic Dehalogenation<sup>6</sup>

Two dehalogenation processes are being developed. One would be applicable to liquids with low

<sup>6</sup>Most halogenated chemicals contain **chlorine** rather than other halogens; the processes discussed below are, therefore, often referred to by the term *dechlorination*.

organic halogen content, the other to pure halogenated compounds or liquids with highly concentrated halogenated compounds. The first process would replace halogen (usually chlorine) atoms with hydrogen, detoxifying the original compound or rendering it less stable. The halogen gas generated in the process would have to be treated in a scrubber device. In the second process, the original compound would be oxidized to carbon dioxide and water, and the halogen would take the form of the pure element (e. g., chlorine gas), which could be recovered.

The feasibility of both processes has been established in pilot-scale units, but neither has yet been employed commercially. Both systems are expected to be suitable for use in mobile units, which could be employed at cleanup sites, but would probably be too small for major commercial operations.

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