Review of Air Pollution Control Techniques for Hazardous Waste Treatment and Disposal

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Techniques and approaches for the control of toxic air emissions at treatment, storage, and disposal (TSD) facilities are an important part of the overall hazardous waste management psocess at these sites. Some pollution control techniques speifically address air pollution at or near hazardous waste sites. Many techniques and approaches, however, are indirect mechanisms that have been developed and established to help control and curb the environmental and health effects from air, water, and land pollution.

This chapter first describes the status of hazardous waste management technologies for reduction, treatment, and disposal of hazardous wastes, and describes scientific air pollution control technologies and methods for hazardous waste incineration and secure landfill facilities, Regulatory and societal control approaches, such as facility permit requirement, tax credits, liability insurance, and public pressure, are then discussed as indirect pollution control mechanisms. Finally, current and long-term "true" costs and benefits of various hazardous waste management technologies and pollution control equipment are discussed, pointing to the need for new and improved approaches for assessing long-term costs/benefits of environmental pollution control technologies and approaches.

Scientific and Engineering Methods

Treatment and disposal technologies are currently available for nearly every known hazardous waste. No single technology, however, is a panacea for handling all waste types. The choice of the best practicable approach for treatment and/or disposal of a given waste depends on many factors, including cost, waste type and volume, availability and suitability of treatment ordis posal facilities, and safety standards. Figure 1 illustrates three general technology options that have to varying degrees been incorporated into hazardous waste management approaches. Table 3 lists in greater detail the strengths and weakenesses of currently available hazardous waste management technologies.

The first technology option, reduction or elimination of waste material, is preferalbe in terms of economic return as well as short- and long-term prote-

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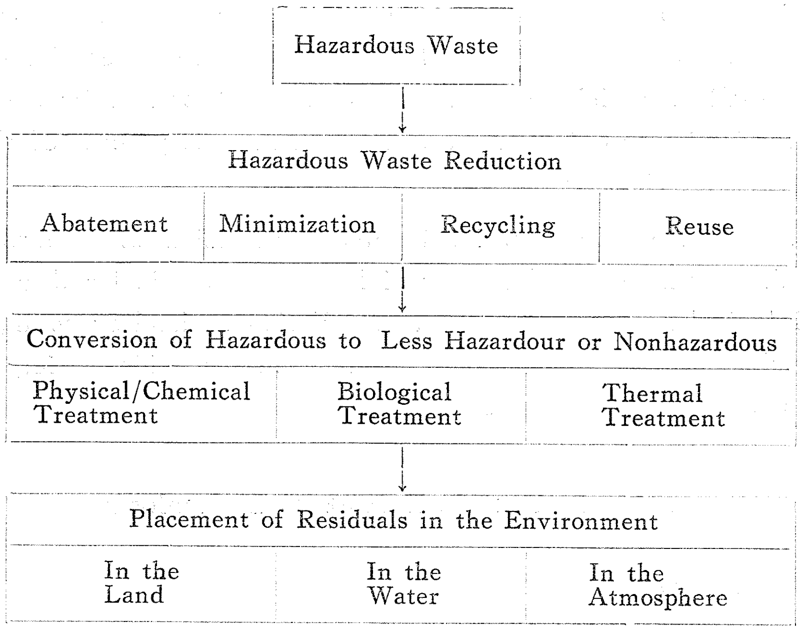
Figure 1 Waste Management Options



Source: National Research Council. *Reducing Hazardous Waste Generation—An Evalutation and a Call for Action*, National Academy Press (1985), p. 11

ction of the environment and public health. It involves process modification or recovery and reuse of waste materials. Waste abatement and waste minimization generally apply to in-plant process modifications; waste reuse and recycling are techniques that can be used either on or off the site of generation.

Waste abatement refers to substitutions of chemicals or changes in production processes to eliminate or greatly reduce the quantities of waste produced. Technologies for abatement usually are referred to as low-waste or non-waste technologies. *Waste minimization* reduces the quantity of waste produced through good housekeeping practices, frequently entailing relatively low capital costs. For example, waste minimization approaches may involve reducing the amount of waste that must leave the site or lowering the handling, shipping, and even treatment and disposal costs. Current documentation and experience suggest both that waste reduction efforts in the U. S. still are in the early stages, and that considerable opportunities exist for drastically reducing generation of hazardous waste.[10]

waste reuse there is generally little modification to the waste. With *recycling*, valuable components of the waste must first be separated from the rest of the waste stream, then recovered for recycling--generating a residue that still must be managed. Recycled wastes include those that are reused, e. g., as raw materials in production processes; or reclaimed, e. g., by solvent redistillation, scrap metal reclaimed by a secondary smelter, or waste blending to make fuels. To date, only a small portion of the total quantity of hazardous waste is actually beneficially used, reused, recycled, or reclaimed--in fact, the estimate for 1981 was only four percent, with over 80 percent of the recycling done at generator sites.(21)

The second technology option involves conversion of hazardous waste to less-hazardous or non-hazardous material through chemical and physical techniques, biological treatment processes, assimilation by land or ocean, or thermal methods using heat or open flame. Table 1 lists a wide variety of generic techniques for each treatment categories.

Table 1 Generic Treatment Technologies

Physical/chemical	
Neutralization	Electrophoresis
Hydrolysis	Freeze drying
Reduction	Freeze crystallization
Precipitation	Chlorinalysis
Evaporation	Catalysis
Dechlorination	Photolysis
Oxidation	Electrolysis
Stripping	Dewatering
Ion exchange	Membrane technology
Liquid ion exchange	Thickening
High-energy electron beam	Emulsion breaking
High-gradient magnetic separation	Adsorption techniques
	Land treatment
	Solvent extraction
Biological	
Activated sludge	Waste stabilization ponds
Aerated lagoons	Mutant bacteria
Anaerobic digestion	Deep shaft aeration
Composting	Fluidized bed bioreactor
Enzyme treatment	Powder-activated carbon
Trickling filter	Land treatment
Rotating biological disc	Municipal sewage treatment plants

Thermal

Rotary kiln	Liquid injection
Fluidized bed	Vertical tube reactor
Molten salt	Infrared furnace
Plasma arc	Co-incineration (industrial boilers)
Cement kiln	Ocean incineration
Microwave plasma discharge	Evaporation
Multiple hearth	Calcination
Pyrolysis	Wet air oxidation

Source: National Research Council, *Reducing Hazardous Waste Generation—An Evaluation and a Call for Action*, National Academy Press (1985), p. 62

Basically, these technologies fall in two primary classes:

1. Incineration, thermal treatment, chemical, physical, and biological processes, which convert wastes from a hazardous to a less-hazardous or non-hazardous state, but also produce a residue, either as a by-product or as a waste stream. This residue in turn must be discharged to the environment or stored; it may or may not have an adverse impact on public health and the environment, depending on the soundness of the approach used for its management.

2. Land treatment and ocean assimilation, which convert the hazardous wastes, bltauso become the ultimate disposal site.

   According to a 1984 EPA report, 66.5 percent of 71.3 billion gallons of hazardous wastes managed at TSD facilities during 1981 was treated. Significant portions, however, also were stored and/or later disposed. Surface impoundments handled the largest single portion of hazardous waste treatment, apporximately 35 percent of all wastes treated; treatment tanks accounted for 18 percent; and incineration the ieast amount estimated at slightly less than one percent of hazardous waste.(21)

   The third option in the simplified waste management hierarchy includes techniques and methods for placement of residuals in the environment. Table 2 lists some generic classifications for these storage and disposal methods.

To date, disposal of hazardous waste has been the most prevalent waste management option. According to EPA figures for 1981, 58 percent of wastes dsiposed were by underground injection, 38 percent into pits and lagoons, and 5 percent in landfills.(21)

Table 2 Options for Placement of Residuals in the Environment

Secure landfill	Seabed implacement
Engineered landfill	Above-ground storage
Structural landfill	Co-disposal
Deep well injection	Land treatment
Ocean disposal	
Geologic isolation	

Source: National Research Council, *Reducing Hazardous Waste Generation—An Evaluation and a Call for Action*, National Academy Press (1985), p. 63

Storage of hazardous waste can occur at all phases of the waste management process. Methods vary according to the type of waste, compatibility of different wastes, anticipated storage time, eventual management option for the waste, and other considerations. Common forms of storage include barrels, lined or unlined bulk metal or concrete tanks; and lagoons and impoundments. For 'perpetual' storagə, secure landfills and underground caverns usually are used.

Storage of waste is a very important step in the hazardous waste management process, accounting for about half of all hazardous wastes managed by TSD facilities during 1981. Surface impoundments were used to store anestimated 38.6 percent of all hazardous wastes stored; tanks were used for about 14 percent; storage containers for .45 percent; and waste piles were used to store roughly 1 percent of hazardous wastes.(21)

Perpetual storage techniques attempt to place the waste in highly condensed or concentrated configurations to prevent hazardous constituents from moving. Generally, little or no conversion from a hazardous waste occurs. Thus, monitoring and migration prevention measures are required for an indefinite period. Experts agree that 500 years may be realistic time estimate for concern and care for hazardous wastes in landfills and perpetual storage options.(9) By constrast, regulations under Subtitle C of RCRA establish 30 years as the period of concern for secure landfills.

Pollution control technology for hazardous waste incinerators

Hazardous waste incineration involves thermal oxidation of industrial wastes mostly organics in a combustion reactor, with ash, combustion flue gases, and heat produced. Typically, CO_2, H_2O, and ash are the products; other combustion products such as SO_2, NO_x, Cl_2, HCl, and metal oxides also may be present and require control.

Air pollution control devices are considered an essential part of any incinerator system because of emissions taking place during the process. The degree of control required depends on feed waste composition, expected level of trace toxic emissions, and rrsulting impact on ambient air quality. Effective controls for inorganic particulates and acid gas emissions from hazardous waste incinerators require a wet electrostatic precipitator, high energy venturi scrubber with mist eliminator tower, or plate-type scrubbers with packed bed. It should be noted that dry electrostatic precipitators and fabric filters are incapable of removing gaseous pollutants without extensive modification. Both the wet electrostatic precipitator and the scrubbers are capable of simultaneously absorbing gas and removing dust. However, each device has certani limitations. For example, wet electrostatic precipitators have a relatively high capital cost, low gas absorption efficiency, sensitivity to changes in flow rate, problem with disposal of wet dust collected, and high corrosion damage expectations with halogens. The limitations of scrubbers include corrosion and erosion problems with metallic construction, wet dust collection, high pressure drop, and requirements for a settling pond for closed-loop operations.[(16]

To help remedy such shortcomings, a more effective approach to emission control may be to improve current incinerator design and operating conditions to minimize the use of expensive air pollution control equipment. For example, for efficient incineration, the oxidation process must be dominant with pyrolysis incidental to the oxidation. Alternatively, the waste may be converted into a more advantageous physical form for oxidation.

Another approach for more efficient incineration is to use enriched air, i. e., containing more than 21% oxygen, instead of excess air, which reduces the rate of oxidation through the combustion temperature and diluting the concentration of reactive intermediates. Air contains only 21% oxygen; the remaining 79% is inert gases, e. g., nitrogen and argon, that contribute nothing to the incineration process, but absorb useful heat and are discarded as flue gases. The increased volume of flue gas from the increased excess air requires a larger capacity for the incineration unit and the gas cleaning equipment. Thus, use of enriched air may be a preferred alternative to excess air especially for incineration of highly toxic wastes that require much higher temperatures to ensure the destruction of toxic components.[(16)]

Shen's experimental results have indicated that at a constant fuel flow rate, the flame temperature of a burner increases exponentially with increasing oxyges enrichment.[12] When the combustion was enriched to contain 27% oxygen, the flame temperature measured 1540°C; using air without enrichment (21% oxygen), the flame temperature measured approximately 1280°C. Experiments also have shown that enrichment incineration is more effective and economical if applied at the secondary combustion chamber.

Monitoring systems for hazardous waste incinerators include waste feed, combustion control, and stack gas monitoring. Controls of the feed rates and waste composition are essential to meet proper incineration requirements such as heating value, viscosity, percent halogen, perecnt ash, specific metals, sulfur, phosphorus, sodium, silicon and acidity. For combustion control, four parameters are critical: oxygen, temperature, turbulence, and residence time. Stack gas monitoring includes testing for concentration of carbon monoxide, carbon dioxide, excess oxygen, particulate matter, and hydrogen chloride.

EPA stack emission criteria require:

1. Process incinerators that burn hazardous wastes, including PCBs, at a control efficiency of 99.99% of the toxic components;
2. Particulate emissions to be less than 180 mg/scm^3 (0.08 gr/scf) when corrected for the amount of oxygen in the stack gas, i. e., 14/21%-O_2;
3. Fugitive emissions to be controlled; and
4. Emissions of HCl to be controlled so that they do not exceed the larger of 1.8 kg/hr or 1% of the HCl in the stack gas.[4]

An owner/operator of a TSD facility may demonstrate compliance with these requirements either by conducting a trial burn, or by submitting data based on previous burns of similar wastes in a similar facility. The purpose of stack testing is to determine compliance with the emission criteria. If a trial burn is conducted, sampling and analysis requirements for incinerator effluent characterization (stack gas) must include:

1. Quantitative analysis of the stack exhaust gas for concentration (mass emissions) of the designated Principal Organic Hazardous Constituents (POHCs),
2. Quantitative analysis of the stack exhaust gas for concentration (mass emissions) of particulate matter,
3. Quantitative analysis (in some cases) of the stack exhaust gas for the concentration of hydrochloric acid for purposes of calculating a removal efficiency and/or emission rate,
4. Determination of the oxygen concentration in the stack exhaust gas for the

purpose of calculating the excess air level in the exhaust gas, and
5. Continuous monitoring of carbon monxoide in the stack exhaust gas.

Because each hazardous waste incineration trial burn represents a unique situation, it is especially important that appropriate Quality Control (QC) procedures be incorporated into sampling and analysis protocols. QC procedures should include three replicate test runs for each trial; preparation and analysis of field and laboratory blank samples; determination of recovery by spiking samples with surrogates; spiking of split samples with POHCs; analysis in duplicate of extracts of some samples; and analysis of calibration standards.

Pollution control approaches for secure landfill facilities

The objective of secure landfills is to isolate wastes physically from the surrounding environment. The landfill is designed to provide long-term containment of wastes and to prevent escape of both leachate and gas from the site. Properly designed and operated secure landfills reduce the mobility of waste to groundwater, minimize the release of wastes to the air, and allow valuable materials to be reclaimed when the technology becomes available. Figure 2 shows a typical design of a secure containment landfill intended to prevent both leachate and gas from escaping from the landfill for 30 years after proper closure of the facility. It should be emphasized, however, that the design, operation, and monitoring of contemporary landfills is essentially a new technology, roughly a decade old, and that much is still unknown about the long-term landfill behavior. In fact, the containment approach is designed to provide protection for a finite period of time and does not address the environmental impact after the design period has elapsed. Thus, further research is needed to assess the long-term pollution problems related not only to groundwater contamination, but also to toxic air emissions escaping from secure landfill sites long after they have been closed.

Data have shown that secure landfills containing toxic organic wastes can be expected to emit various halogenated organic and toxic materials, although levels and quantities of emissions may vary widely depending upon the nature and properties of the wastes and the surrounding environment, including temperature and moisture content. Volatization and degradation processes are very slow and landfill gases generated may persist for many years, until all constituents of in-place wastes achieve chemical equilibrium and all biological materials have been exhausted.(14)

Where volatization is considered a potential problem, specific control and monitoring measures must be applied. These include three basic approaches for controlling toxic gaseous emissions from landfills containing toxic organic wastes.

1. **Prevention of gas generation** by preventing placement in landfills of all organic sludges, volatile organic wastes, and liquids. The November 1984 RCRA amendments partially address this problem, banning from landfills non-containerized liquid hazardous wastes, and requiring EPA to promulgate regulations within the next few years to minimize or ban land disposal of certain liquids.

   Sludges and organic wastes will readily generat egases and leachate also is known to contribute a significant amount of gases. Thus, liquids containing organic compounds in hazardous waste landfills must be controlled due to their potential for contamination of underground water, and because they can potentially contaminate ambient air at or near landfill sites. Keeping rainwater both from entering and leaving landfills eventually would minimize gas emissions. Liquids in landfills may come from precipitation, surface runoff, and underground seepage; the hydraulic head created by liquids is the driving force which causes landfills to leak. Liners, made either of concrete, asphalt, certain plastics, or a mixture of natural soil and sodium bentonite, are used to create an impermeable layer. The use of two or more liners with leachate collection systems between them is now required under the 1984 RCRA amendments for new landfills, surface impoundments, and extensions of existing landfills.

2. **Pretreatment of the waste and installment of a gas collection and control system** are successful methods for control of air pollution problems at or near hazardous waste sites. Pretreatment mechanisms that may limit the amount of volatized wastes include sorption, biodegradation, or any other techniques that will destroy or recover hazardous components for reuse and/or convert hazardous waste to innocuous forms that are acceptable for land disposal.

   Gas collection and control systems also may be used to collect vapors and direct them to treatment systems. Basically, gas collection and control systems are designed to prevent fugitive emissions of toxic vapors and may consist of trenches, wells, perforated pipes, an impermeable cap, connecting pipes, and a pump. The gravel-filled trenches and wells interycept laetrall migrating gases and provide a low resistance path in the wells and trenches. Exact spacing of the wells depends on the waste properties; the well depth should equal 3/4 of the depth of the waste, and the top of the wells and trenches must be sealed with an impermeable cover. The landfill generated gas is extracted from the wells and trenches by sub-surface pipes with natural or forced gas movement. The pipes are connected to a pump by a common header pipe leading to an adsorption control system which removes the toxic gaseous emission prior to discharge into the atmosphere. Perforated pipes also may be inserted vertically into the wells and trenches to collect gases. A gas collection system may be differently designed and constructed by placing the perforated pipes horizontally between the top of the waste cell and the bottom of the impermeable cap.(14)

3. **Capping a chemical waste landfill** with a thick emission barrier or organic topsoil or clay reduces the volatization rates by several orders of magnitude.(17) Other materials such as paper mill sludges and manure also have been used effectively to cover landfills and prevent PCB volatization under certain atmospheric and other conditions.(14) Theoretically, the thicker and less permeable the cover, the lower the rate of gas emission; the more organic the content in the cover, the higher the absorption of undesirable gases.(14)

Regulatory and Societal Approaches

In addition to scientific and engineering methods, indirect mechanisms which may contribute to the control of toxic air and other pollutants at or near hazardous waste sites include a number of regulatory and societal approaches. For example, the hazardous waste management program under Subtitle C of RCRA prescribes standards and requirements specific to generators, transporters‘ and owners/operators of TSD facilities, but also incorporates steps and Procedures designed at controlling all aspects of the hazardous waste management process. These include the use of the manifest system which mandates continuous accountability of hazardous waste movement from point of generation to point of ultimate disposal; the EPA permit program; and the role of enforcement as a controlling force to help assure adequate and appropriate hazardous waste management practices. Other indirect methods of pollution control include tax credits, liability insurance, and public pressure.

Under Subtitle C of the RCRA regulatory program, all owners/operators of hazardous waste management facilities in existence prior to November 19, 1980, were mandated to submit an application by that date for a *permit* to continue operation. All applications submitted to EPA-or to a state authorized to conduct its own hazardous waste program-must meet basic provisions regarding application, permit conditions, and reporting procedures.

The RCRA permit application contains two parts:
Part A seeks miscellaneous information such as name, location, ownership, and company status, etc. It also seeks more specific information such as;

- whether the facility is new or existing, and whether the application is first or revised;
- for existing facilities: (1) a scale drawing showing TSD areas, past and present, and (2) photos clearly delineating all existing structures and existing/potential TSD sites;
- TSD processes and design capacities;
- specification of hazardous wastes, estimated annual quantities, and processes to be used;
- topographic or other maps, depicting TSD facilities, wells, water bodies, etc., and other information;
- nature of business; and
- all permits or construction approvals received or applied for under various regulatory programs.[2]

Information for Part B is of two different kinds: (1) general information required of all RCRA applicants; and (2) facility-specific information on the particular type of treatment, storage, and disposal operations (e. g., landfill, surface impoundment, tanks, containers, incinerator, land treatment). Technical data such as design drawings and specifications, and engineering studies, must be certified by a registered professional engineer. [2] The general information required for RCRA applicant is extensive and can require special documentation such as engineering studies, e. g., chemical, hydrogeological, and geological analyses, and planning and financial analyses.

In addition, to guard more fully against potential toxic emissions, the permitting process should require information on hazardous emissions at or near TSD facilities, especially land disposal sites. These data should be evaluated prior to the issuance of RCRA and other relevant permits. The evaluation should include short-term and long-term effects of toxic air emissions on human health and the environment on the basis of ambient air analysis at or near the site. Information relating to the quantity of hazardous air emissions, the toxicity of volatile compounds, and consideration of control measures should be required. If the screening process results showed a potential air pollution problem, ambientair monitoring data definitely should be required.

Tax credits encouraging the use of waste reduction methods or waste treatment and disposal technologies known to be most environmentally sound, also can function as an incentive not to pollute. Tax credit-related approaches could include:

1. Low-or no-interest loans, with liberal repayment plans, for waste reduction or waste treatment improvement expenditures.
2. Guaranteed loans to firms by private investors, to facilitate financing of waste reduction measures, or improvement of hazardous waste treatment technology.
3. Tax reduction, or tax credits for waste reduction and waste treatment initiatives, or exemptions from the sales tax or import duties for treatment, recovery, or reduction equipment.
4. Direct government subsidies to firms developing treatment or reduction technologies to minimize initial investment costs.
5. Government actions allowing and encouraging smaller firms to pool their resources to implement joint reduction strategies or construct and operate joint resource recovery facilities. [10]

Taxes and restrictions on landfilling of certain hazardous wastes and *waste-end taxes* on generation of hazardous wastes are other indirect control mechanisms designed both to decrease the volume of hazardous waste produced, and increase the competitiveness of other waste management options with secure landfilling.

Specifically, the waste-end tax concept suggested in a 1983 Office of Technology Assessment report [11] and endorsed by many Superfund reauthorization supporters, advocates replacing the current Superfund tax on feed stock with a system in which companies would be charged according to the amount of hazardous waste they generate. The "waste-end" tax approach is generally supported by the petrochemical industry, one of the principal contributors to the current Superfund. As illustrated in Table 3, this approach is designed to encourage what are considered preferable hazardous waste management techniques by creating economic incentives for waste recycling and reduction. Recycled wastes and wastes used for energy production would not be taxed. Under this concept, costs of managing hazardous wastes also would be spread throughout industry.

Table 3 Illustration of a Hazardous Waste Generator Tax Structure

Waste management category	Tax on solid waste (S/tonne)	Tax on liguid waste (S/tonne)
Land disposal	42	85
Offsite:		
Land disposal after treatment ···	21	42
Treatment..............................	11	21
Onsite:		
Land disposal after treatment ···	11	21
Treatment	5	11
Recycling/reuse;		
Used crankcase oil	0	0

NOTE: In addition to this tax, to support a State Superfund, a hazardous waste generator fee (a minimum fee plus a fee dependent on the quantity of waste generated) was also proposed to support State administrative costs for hazardous waste programs. A provlsion was included to exempt small generators.

SOURCE: Minnesota Conference Report H.F. No. 1176, Mar. 19, 1982.

Similarly, the *financial and legal liabilities* of generators for cleanup costs on abandoned hazardous waste disposal sites, and the liability of owners/operators of TSD facilities for failure to respect permit requirements under RCRA and other regulatory statutes, undoubtedly are among the most powerful deterrents to pollute. Specifically, many generators have become aware of the potential long-term costs of land disposal of hazardous wastes. With the possibility of additional liability requirements through expansion of cleanup liability and potential civil liability to injured third parties, companies may very well choose to refine/change their waste management practices in their effort to reduce their long-term liability.

In order to address liability coverage needs both during the operating life and following closure of a TSD facility, some liability insurance mechanisms have been created. For example, *financial responsibility requirements* for owners/operators of TSD facilities were promulgated in April 1982 under Subtitle C of RCRA. These basically address third-party liability coverage or equivalent self-insurance during the operating lifetime of a TSD facility. Third-party liability coverage assures that owners/operators of TSD facilities bear the full financial consequences for whatever result from their management practices. Financial responsibility rules issued earlier also require that owners/operators of TSD facilities have adequate funds available to properly close their facilities at the end of their useful lives, and to maintain and monitor the facilities for 30 years following proper closure.

Additionally, a *post-closure liability fund* established under the Superfund Act assures financial coverage of unanticipated problems at closed RCRA permitted facilities. The post-closure fund is derived from a tax levied since 1983 on waste disposed at both on-site and off-site facilities. The fund greatly reduces the probability of damage, since problems are less likely to occur at monitored RCRA-permitted facilities and if they should, they will be discovered and corrected more promptly at less expense. Further, the ability to insure against potential future problems allows companies operating these sites to determine the total costs of providing waste management service by building these costs into their pricing structure.

The post-closure liability fund is a needed control and insurance mechanism, since commercial insurance policies are not available to cover in perpetuity damages caused by accidental discharges from disposal facilities. This fund will pay any and all damages for property damage and personal injury, cleanup and restoration of the facility, and long-term monitoring and maintenance.

Finally, *public opinion* is an increasingly powerful mechanism forcing governments and industry to re-examine the short- and long-term advantages and disadvantages of various hazardous waste management practices. For example, in the past several years, public opinion has prevented most attempts at siting new, state-of-the-art hazardous waste management facilities. In fact, it is highly unlikely that facilities such as secure landfills can ever again be sited in the U.S. It can be argued that existing regulatory statutes and the post-closure liability fund and other mechanisms discussed above, should help reassure prospective host communities that new hazardous waste management facilities will meet rigorous tests of environmental safety and financial responsibility. In addition, various mechanisms now in place should reassure the public that, in the event of any unanticipated problems with the facility, money will be readily available for all cleanup and restoration costs and for compensation of property and personal injury.

However, resistance to siting of new facilities and to living near existing facilities are rooted in the public's fear of what it perceives as the "concentrated risks" a hazardous waste facility may bring to the host community. These perceived risks are based on images of Love Canal, Times Beach, and other sites where groundwater contamination, air pollution, and adverse health effects such as birth defects and cancer have been discovered and documented. The public also fears social 'costs' related to the quality of life, including adverse zoning decisions, devaluation of property, and transportation hazards. The anticipated benefits of the new facility are regarded as relatively diffuse compared to the perceived concentrated risks.

Cost Comparison

Evaluating costs versus benefits of using certain hazardous waste management technelogies and of installing pollution control equipment requires analysis of several factors. For instance, not only the current costs, but also the long-term 'true' costs should be considered in assessing which is the most appropriate option. Similarly, the actual cost of air and other pollution control equipment should be balanced against the long-term economic, environmental, and health benefits resulting from such pollution control devices. To date, however, no model exists to assess accurately the long-term costs and benefits of using waste management and pollution control practices known to be environmentally preferable, even if they are more costly in the short-term.

Comparing the current costs of various types of hazardous waste management technologies must include cost variations among different types of systems within a given technology, as well as the capital and operations costs of each technology. For example, the cost of incineration is generally higher than that of other treatment and disposal alternatives. However, within the incineration technology, costs of different incinerator systems are difficult to compare because of significant variations in waste characteristics and volumes, type of incinerator and related equipment, and numerous operating expenses related to local conditions.

For example, among process incinerators, rotary kilns involve the highest capital and maintenance costs, while liquid injection process incinerators have the highest operating costs due to expensive fuel feed and emission control systems. Costs also can increase significantly if the incinerator system includes standby equipment, safety provisions, fully automated operations, expensive construction materials, or other custom features, and liability insurance. As for incineration fees, they usually are based on the heating value of the waste, its chemical nature, viscosity, annual quality required to be incinerated, ihe type of container, transportation, and other costs.

Waste treatment technology includes a host of unit processes for biological, chemical, and physical treatment of wastes. The costs vary considerably depending on the unit processes used to treat the waste stream and the volume of residual waste atill needing disposal following treatment.

Deepwell injection remains the lowest cost option for disposing of liquid wastes. However, ɔommercial deepwell disposal services are available only in the Midwest and the Gulf Coast, and the long-term safety of deepwell injection remains a controversial issue.

The price of landfilling hazardous waste has substantially increased in the past few years, due to increased operating costs and more stringent regulatory requirements for pretreatment and special handling of many waste streams prior to landfilling. These costs could further increase under proposed amendments of the Superfund Act, which recommend a $10.00/ton tax rate, rising to $16.00/ton in 1990, to discourage landfilling of hazardous waste. This 'waste-end' tax, to be paid by owners/operators of TSD facilitier, is four times the proposed rate ofr disposal at treatment facilities os ocean dumping.

According to a 1984 U.S. EPA report to Congress on clean air and water costs [19], the total cost of compliance with clean air federal regulatory requirements, including capital investment in pollution control equipment and operation and maintenance expenses, is estimated at $256 billion for the ten-year period 1981-1990. About $102 billion, or 58 percent relates to requirements of the Clean Air Act (CAA). For the period 1979-1984, air pollution control costs were $126.5 billion, while capital investment costs were $100.3 billion for both air and water pollution control.

According to the report, the highest costs for air pollution control are expected to be in the fuels and energy category, which includes electric power plants, petroleum refining and coal mining. Expenditures totaling $98.3 billion are anticipated. Costs to control air pollution from vehicles, aircraft, and other mobile sources are projected to run to $80.6 billion for the same period. Unfortunately, the report only addresses the costs of environmental regulations and does not attempt to assess the economic, environmental, and health benefits of environmental programs. [19]

If both current costs and long-term 'true' costs could be adequately assessed, it is obvious that good economics in many instances would favor use of waste reduction and treatment technologies over land disposal, and use of pollution control equipment. However, it is extremely difficult to evaluate the economic long-term 'true' costs and benefits accurately because of several factors:

1. The long-term transport and fate of land-disposed hazardous waste cannot now be reliably assessed. Therefore there are significant unknowns in estimating long-term concentrations of toxic air and other pollutants exposures.

2. The long-term health effects from low-level exposures to toxic air and other pollutants at or near hazardous waste sites are largely unknown.
3. There are serious uncertainties as to how to translate health and environmental effects into monetary values, assuming that these effects can be assessed accurately.

4. There is currently no method to assess society's responsibilities to future generations against its responsibilities to current generations. [10]

Table 3 CURRENTLY AVAILABLE HAZARDOUS WASTE MANAGFMENT TECHNOLOGIES LISTED BY TECHNOLOGICAL OPTION

	STRENGTHS	WEAKNESSES
I. WASTE REDUCTION		
A. Source Segregation or Separation	1. Easy to implement; usually low inversment 2. Short-term solution	1. Still have some waste to manage
B. Process Modification	1. Potentially reduce both hazard and volume 2. Moderate-term solution 3. Potential savings in production costs	1. Requires R&D effort; capital investment 2. Usually doesn't have industrywide impact
C. End-Product Substitution	1. Potentially industrywide impact-large volume, hazard reduction	1. Relatively long-term solutions 2. Many sectors affected 3. Usually a side benefit of product improvement 4. May require change in consumer habits 5. Major investments required-need growing market
II. REUSE, RECYCLING AND RECOVERY OF WASTES		
A. Recovery/Recycling-In-Plant (On-site)	1. Moderate-term solution 2. Potential savings in manufacturing costs 3. Reduced liability compared to commercial recovery or waste exchange 4. Recovery of energy for incineration	1. May require capital investment 2. Maynot have wide impact
B. Recovery/Recycling-Commercial (Off-site)	1. No capital investment required for generator 2. Economy of scale for small waste generators	1. Liability not transferred to operator 2. If privately owned, must make profit and return investment 3. Requires permitting 4. Some history of poor management 5. Must establish long-term sources of waste and markets 6. Requires uniformity in composition

Table 3 (continued)

	STRENGTHS	WEAKNESSES
C. Recovery/Recycling–Waste Exchange	1. Transportation costs only	1. Liability not transferred 2. Requires uniformity in composition of waste 3. Requires long–term relationships–two party involvement
III. TREATMENT, DETOXIFICATION AND DESTRUCTION METHODS		
A. Incineration and Other Thermal Destruction	1. Highly effective on organic wastes, except little data on specific constituents 2. Potential for energy recovery 3. Long experience with conventional designs	1. Monitoring uncertainties 2. May release contaminants to air 3. Moderate to high operational costs 4. Not effective on inorganic wastes; e.g., excessive metals not suitable
B. Treatment and Detoxification	1. Highly effective for many metals and other inorganics 2. Can be effective for some organic wastes which can be degradad or removed 3. Many process combinations are available for stepwise application	1. Moderate capital costs 2. Organic wastes may not be effectively treated 3. Waste residuals are produced which require final disposal
IV. LAND DISPOSAL (e.g., Landfills and Surface Impoundments)	1. Low to medium costs 2. Virtually any waste can be physically buried in a landfill	1. Potential contamination of surface and groundwater 2. Questionable integrity of liner 3. Requires long–term monitoring and maintenance 4. Landfill not suitable for liquid wastes; liquids produced (leachate) must be controlled to minimize migration potential 5. May not be effective for volatile and soluble waste constituents

Source: Adapted from Office of Technology Assessment, "Technologies and Management Strategies for Hazardous Waste Control", March 1983.

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