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REGULATORY IMPACT ASSESSMENT FOR PROPOSED HAZARDOUS WASTE COMBUSTION MACT STANDARDS

DRAFT

APPENDICES

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Appendix D

WASTE MANAGEMENT ALTERNATIVES REPORT

MEMORANDUM

TO: Lisa Harris, EPA/OSW; Bob Black, IEc

FROM: Jerome Strauss, Versar, Incorporated

DATE: March 30, 1995

SUBJECT: Evaluation of Alternative Treatment Technologies for Wastes That Are Currently Being Sent to Combustion Facilities (Revised-Draft)

1.0 INTRODUCTION AND PURPOSE

The Environmental Protection Agency (EPA) is currently developing new standards for hazardous waste combustion facilities. If implemented, these changes may result in increased combustion costs for waste generators. In view of this, the Agency is currently conducting a Regulatory Impact Analysis to evaluate how generators and other waste management markets may react to these new combustion standards. One possible reaction may be that generators will consider alternative treatment technologies as a result of increased combustion costs and more stringent standards. EPA wants to assess the elasticity of demand for combustion services by characterizing the availability of alternative treatment options.

The purpose of this memorandum is to assess the potential alternative waste management options available to generators/managers of wastes that are currently combusted. The following discussion presents treatment alternatives available to waste generators that are currently using incineration to dispose of their hazardous waste and presents cost information associated with these alternatives.

2.0 METHODOLOGY

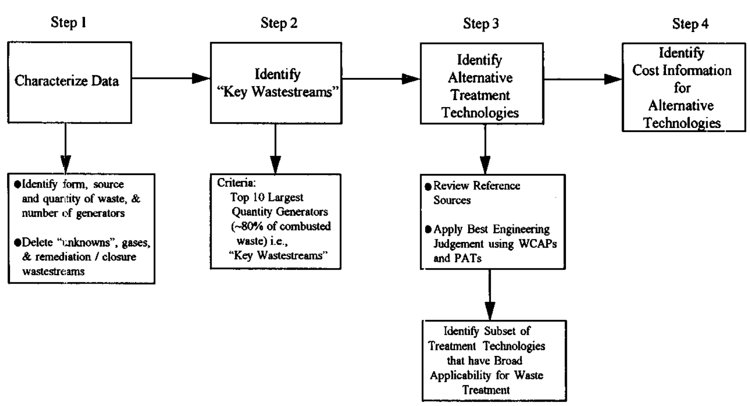
Exhibit 1 provides an illustration of the methodology used to identify alternative treatment technologies for wastes that are currently combusted.

2.1 Data Characterization

The initial activity was to characterize the wastes currently being incinerated. Information on the incinerated wastestreams such as the form (i.e., gas, liquid, solid, sludge, etc.) and source of the wastestream (i.e., production processes, cleaning operations, remediation activities, etc.) provided the basis for characterization.

Exhibit 1

OVERVIEW OF METHODOLOGY FOR IDENTIFYING ALTERNATIVE TREATMENT TECHNOLOGIES FOR WASTES THAT ARE CURRENTLY COMBUSTED



We reviewed data from EPA's Biennial Report Survey (BRS) data base on combusted hazardous wastestreams. Form codes identifying the general physical nature of the wastestream, source codes identifying the general source of the wastestream, and the quantity of waste incinerated were tabulated. The information was then grouped by form code and source code and summarized to give the total quantity of waste burned per group, along with the number of generators in each category. Descriptions of the form codes and source codes are shown in Appendix A; Appendix B lists BRS data by quantity of wastestreams from highest to lowest quantities.

Once the data were collected, the following screening criteria were used to eliminate certain wastestreams from consideration:

- Wastestreams with form codes and source codes that were identified as "Unknown" (PF20 and S14) were omitted because not enough information was known about the wastestream to adequately identify alternative treatment technologies.

- Wastestreams with a form code identified as "Gases" (PF19) were deleted because these wastes were not adequately described to evaluate alternative treatment technologies. Also, these streams were not of sufficient quantity to be concerned with (i.e., less than 0.02 percent of the total quantities).

- Wastestreams with a source code of "Remediation and Closure" (S12) were eliminated because incineration of remediation wastes was considered a one-time, nonroutine occurrence resulting from cleanup activities, and not from continuous/routine operations.

2.2 Selection of Key Wastestreams

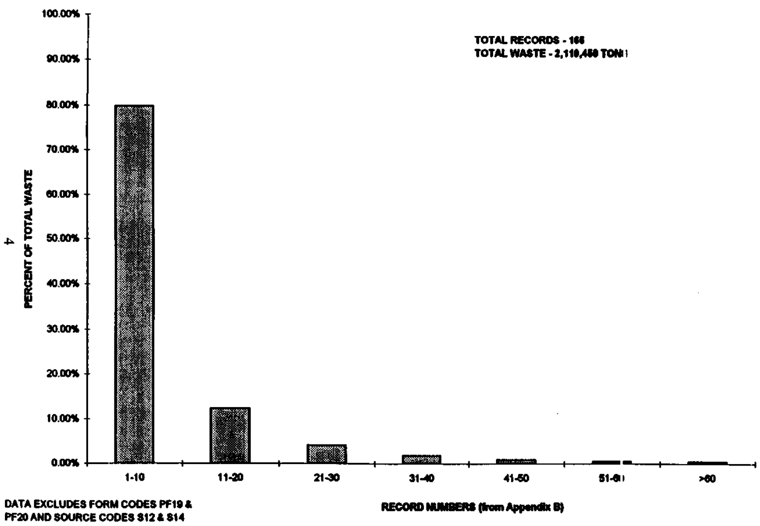
Data were then screened according to the above criteria. There were 230 (20 form codes/and 14 source codes) records in the Appendix B data base. A graphical analysis of the screened data indicated that the 10 largest quantity form code/source code combinations of wastes accounted for nearly 80 percent of the waste being incinerated. (See Figure 1.) These 10 wastes were identified as the "key wastestreams" for evaluating alternative treatment technologies. It was assumed that analysis of these "key wastestreams" would provide the greatest information about the quantity of wastes that could be managed by alternative technologies. These "key wastestreams" were characterized as follows:

- Approximately 40 percent were nonhalogenated solvents and other organic liquids.

- Approximately 30 percent were wastewaters and aqueous wastes.

- The remaining 30 percent were still bottoms, sludges, and halogenated solvents.

Figure 1 - Graphical Analysis of Relative Waste Stream Quantities



The total hazardous waste generation investigated was 3,074,789 tons, of which over 80 percent were generated by the 10 largest form code/source code groups, leaving less than 20 percent generated by the other 155 groups. Those 10 largest groups represented approximately 200 generators (6 percent of the 11,400 generators). Those generators are primarily from the chemical and petroleum refining industries.[1]

2.3 Identification of Alternative Treatment Technologies for Key Wastestreams

Waste management alternatives for these "key wastestreams" were identified from review of a number of available resources, and then from applying best engineering judgment. Some reference sources used included recent work developed by EPA Office of Solid Waste (OSW), Waste Management Division on technologies applicable to combustible wastes, as well as various literature sources pertaining to treatment technologies. The Vendor Information System for Innovative Treatment Technologies (VISITT) Version 3.0 and the Alternative Treatment Technology Information Center (ATTIC) data bases were also researched for potential alternative treatment technologies. The application of best engineering judgment in determining the applicability of alternative treatment technologies involved review of the various Parameters Affecting Treatment Selection (PATS) and Waste Characteristics Affecting Performance (WCAPs). For example, in considering if carbon adsorption is applicable to a wastestream, specific PATS and WCAPs considered might include percent water, temperature, molecular weight of organic constituents, and the cyclic nature of organic constituents.

Once the alternative treatment technologies were identified, the treatment specific information (i.e., waste-feed characteristics, treatment levels, cost factors, etc.) were collected and summarized. (See Table 2.)

3.0 ASSUMPTIONS

The following assumptions were made in determining the applicability of alternative technologies for wastes that are currently being combusted.

1. The analysis was performed on a nonspecific industry basis. That is, wastes of the same form and from similar sources could be treated with the same or similar alternative technologies regardless of the industry generating the waste. For example, wastes with low biological oxygen demand relative to total organic content would be amenable to biological treatment regardless of whether the wastestream was derived from chemical industry synthesis or petroleum refining.

2. Wastestreams were assumed to be mostly organic in nature. Inorganic and high-concentration metals wastes would not normally be treated using incineration;

[1] Consistent with the regulated universe under the proposed MACT standards, the waste analyzed is burned at commercial BIFs, commercial incinerators and on-site incinerators. Waste burned at on-site boilers is not considered.

therefore, alternative technologies applicable solely to the treatment of inorganics and metals would be considered not applicable.

3. Of the wastestreams considered, only those described as wastewaters were considered aqueous (i.e., less than 1 percent total solids).

4. As discussed earlier, all form codes and source codes labeled "Unknown" were eliminated. All wastestreams with a form code labeled "Gas" were eliminated, and all wastestreams with a source code labeled "Remediation and Closure" were eliminated.

5. In considering applicability and costs, technologies that were demonstrated at the bench-scale level were not considered because these are emerging, non-demonstrated technologies, and information on the effectiveness of the treatment and the related cost information would be speculative.

4.0 ALTERNATIVE TREATMENT TECHNOLOGIES ANALYSIS AND ASSOCIATED COSTS

4.1 Identifying Applicable Technologies

This section and Appendix C briefly describe technologies that can be used for alternative treatment of the subject wastes that are currently incinerated. These technologies are applicable to the types of waste discussed in Section 2. The applicability of these technologies were based on the types of wastes that are currently incinerated, the Parameters Affecting Treatment Selection (PATS), and expected Waste Characteristics Affecting Performance (WCAPs). It must be noted that we have made general determinations regarding the applicability of these technologies. Typically, detailed information on wastestream composition is needed to determine the specific applicability of a technology to a particular wastestream. For example, wet air oxidation is principally applicable to wastewater streams containing less than 5 percent organics. As discussed in Section 2 and tabulated in Appendix B, the data for wastes that are currently incinerated suggest the majority of these wastes are likely to be primarily organic wastestreams containing relatively few metals and inorganic constituents. However, there is very little information to suggest the quantitative organic content of any of the streams. Hence, this section focuses on technologies that are generally applicable to organic wastestreams.

Many technologies were determined to be inappropriate as alternative technologies for wastes that are incinerated. Technologies were eliminated from consideration as potential alternative technologies for one or more of the following reasons:

- The technology was not applicable to wastestreams designated "key wastestreams" (i.e., wastestreams representing the top 80 percent of the waste generation quantities).

- The technology was an emerging/innovative technology with limited information and cost data. (In some cases the emerging/innovative technology was a variation of a technology discussed in more general terms in this report; that is, the basic principles of operations were similar.)

- The technology is demonstrated only at the bench-scale level.

The technologies that were identified as potential alternative treatment technologies for wastes that are otherwise incinerated are listed in Table 1 and discussed in Appendix C. None of the selected alternative treatment technologies destroy hazardous waste components by the application of combustion, though pyrolysis, wet air oxidation, distillation, dehalogenation, and supercritical oxidation may employ temperatures that are higher than ambient. As also noted in Table 1, several of the alternative technologies have only limited applicability to the waste streams being evaluated. These technologies include: chemical oxidation, cross-flow evaporation, dehalogenation, hydrolysis, pyrolysis, photocatalytic oxidation, supercritical extraction, supercritical oxidation, and wet air oxidation. For instance, dehalogenation is limited to aqueous wastes contaminated with certain halogenated organic compounds. Wet air oxidation is limited to a narrow range of wastestream properties, and typically does not destroy a relatively significant portion of the organic contaminants. Other technologies, also noted in Table 1, are only in the early stages of development and utilization, and would be risky choices (e.g., hydrolysis, photocatalytic oxidation, supercritical extraction and supercritical oxidation).[2]

Table 1 also notes that at least two of the alternative technologies are sensitive to contamination with heavy metals. Specifically, biological treatment may be "poisoned" if metals are present in toxic concentrations, typically at concentrations of a few mg/l (or mg/kg). Likewise carbon adsorption may not be as effective, because some metals, like mercury, will preferentially adsorb to the carbon granules. Because combusted wastes often contain metals, the applicability of these technologies is probably limited.

4.2 Cost Analysis

Cost information was obtained primarily from the Alternative Treatment Technology Information Center (ATTIC) data base and is summarized in Table 2 with additional discussion in Appendix C. Other sources were searched to find cost information on technologies not found in the ATTIC data base. In general, for the technologies investigated, ATTIC did not contain adequate information on the cost of treatment that would be charged by vendors (i.e., commercial treatment, storage, and disposal facilities). In some cases, ATTIC provided the capital cost of constructing a treatment system and an incremental cost of waste treatment. If the only information provided by ATTIC was for the treatment of soil by a particular technology, that information was used as a rough estimate of cost. If other treatment cost information was available, the soil information was not included. Finally, treatment costs are

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[2] It must be noted that treatment technologies are often combined to form treatment trains. For the purpose of this report, technologies and associated costs are assumed to include all required pre-treatment and/or post-treatment. This report does not include technologies, such as neutralization, equalization, and settling, that are primarily used for pre-treatment/post-treatment relative to the "key wastestreams."

sensitive to design factors, such as economy-of-scale or removal design requirements. Therefore, the cost information is good to (±) a factor of 2.

As reflected in Table 2, operating costs for aqueous streams are typically expressed as dollars per 1,000 gallons. Operating costs for other wastestreams are given as dollars per ton. Treatment operating costs for aqueous streams range from as little as $0.25 per 1,000 gallons for chemical oxidation to as much as $70 per 1,000 gallons for wet air oxidation. For nonaqueous streams, the costs range from as little as $24 per ton for supercritical oxidation, and hydrolysis to as much as $3,200 per ton for some forms of pyrolysis.

As noted, many of the treatment technologies that have been identified **separate** the hazardous components from the non-hazardous residuals (e.g., distillation), as opposed to **destroying** the hazardous component (e.g., biological treatment). Therefore, there are 2 waste streams leaving the treatment technologies; i.e., the non-hazardous residual, and the hazardous constituent stream. With the exception of carbon adsorption technology, the separated hazardous constituent stream is assumed to be a liquid that is essentially organic in nature. For carbon adsorption the separated organic is attached to the solid carbon particles, and would be disposed of as a solid. The treatment costs shown on Table 2 include the cost of treating the hazardous constituent stream by incineration. It has been assumed that incineration costs are $284 per ton of liquid (4.2 tons per 1,000 gallons), and $1,325 per ton of solid. It has also been assumed that for the technologies of: gravity separation, pyrolysis, solvent extraction, and supercritical extraction, that the hazardous constituent stream is only 1 percent of the original wastestream. For air stripping, carbon adsorption, and cross flow evaporation it is assumed that the hazardous constituent stream is 0.01 percent of the original waste (i.e.,100 ppm), and for distillation, it is assumed that the hazardous constituent stream is 10 percent of the original waste. Additionally, for carbon adsorption, it is assumed that the carbon removes 1 percent of its weight in hazardous constituents.

It should also be noted that in many cases, the hazardous constituent stream is recoverable. For instance, in distillation, the distilled stream may have value as a solvent. For activated carbon, the adsorbed organic hazardous constituents may be desorbed as a vapor by application of heat, and recondensed for reuse as solvents. If recovered, the hazardous constituent stream is likely not to further adversely impact treatment costs, or perhaps even have a desirable effect (i.e., the value of the recovered solvent). Recovery of the hazardous constituent stream has not been considered in this analysis, only additional treatment by incineration.

All of the technologies have been demonstrated at the full- or pilot-scale. However, some are not readily available commercially, but may be constructed onsite if desired. Examples of those technologies that are not as likely to be commercially available are: photocatalytic oxidation, supercritical extraction, supercritical oxidation, and pyrolysis. Table 2 also notes (last column) which technologies are typically constructed on the generator's site. The ones that are not usually built onsite are fairly complex and/or require substantial capital investment.

5.0 CONCLUSIONS AND CAVEATS

In the data base available for review there were 230 record groupings (form code/source code combinations); e.g., PF06 (wastewaters and aqueous wastes)/ S07 (process waste removal and cleaning), representing 11,400 generators. The total hazardous waste generation represented by all generators was about 3 million tons. It is of interest to note that of those 3 million tons, over 80 percent were generated by the 10 largest record groups, leaving less than 20 percent generated by the other (approximately) 155 groups. The generators are primarily from the chemical and petroleum refining industries.

The information in the data base gives only general descriptions about the characteristics of the wastestreams. Therefore, it is difficult to say definitively what alternative treatment technologies would be applicable to a particular record group. However, 16 alternative technologies were identified based on best engineering judgement for each record grouping description.

Table 3 matches the wastestreams (form code/source code combinations) with the potentially applicable technologies. As shown, we estimate that a large quantity of waste -- about 1.6 million tons -- potentially could be managed with the alternative technologies. The vast majority of this waste is either low-concentration aqueous waste or solvent-based waste. Each wastestream has a number of technologies that are potentially applicable, although many of these technologies may be limited by the degree to which the alternative is technologically established and by constraints on the types of wastes that can be handled (e.g., metals-bearing wastes). Overall, five technologies appear most applicable: air stripping, distillation, gravity separation, solvent extraction, and ozonation.

For each alternative technology VISITT and ATTIC databases, as well as other sources were consulted to determine the cost of each technology. Treatment operating costs for aqueous streams range from as little as $0.25 per 1,000 gallons for chemical oxidation to as much as $70 per 1,000 gallons for wet air oxidation. For non-aqueous streams the costs range from as little as $24 per ton for supercritical oxidation, and hydrolysis to as much as $3,200 per ton for some forms of pyrolysis.

The costs identified for the technologies raise a key question regarding the applicability of the alternatives. In many cases, the cost of the alternative appears to already be less than the cost of combustion. It is unclear why these technologies would not already be chosen over combustion. Several explanations are possible:

- Our cost estimates may be understated due to the lack of complete and reliable cost information for the alternative technologies.

- In the case of solvent wastes, *average* combustion prices are well above the estimated price of alternative technologies. However, actual prices for high-Btu solvent wastes may be very low; cement kilns and blenders may accept the waste for free or even pay generators for the waste. Therefore, at this level of resolution in prices, the alternative is not cheaper than combustion.

- Liability concerns may make the definitive destruction of combustion more attractive. Most of the applicable technologies are separation, not destruction technologies; this leaves a portion of the waste that must still be managed as hazardous.

- We have noted that our analysis considers wastes characterized at a very general level -- BRS source and form code. At a greater level of detail, there may be characteristics of any given wastestream that preclude use of the technology identified in the analysis. For example, two of the inexpensive technologies are limited for certain waste characteristics. Air stripping is effective in removing volatiles but not semi-volatiles. Ozonation is not effective with chlorinated compounds. BRS data do not provide information at this level of detail.

- An on-site incinerator represents a sunk cost for the generator. The generator will only discontinue burning and implement a new waste management technology if the variable cost of burning is less than the total cost (fixed and variable) of the alternative. This may discourage adoption of the new technology in the short term; however, over the capital replacement cycle, generators may be more likely to adopt the alternative.

Because of these uncertainties, we believe that our analysis may overstate the potential for introducing waste management alternatives.

Table 1: Alternative Treatment Technologies For Wastes Routinely Combusted

Technology	Function	Type of Waste Applicable To *	Form of Waste
Most Applicable Technologies:			
Air Stripping	Separation	3,4	Liquid, Solid
Distillation	Separation	3,4	Liquid
Gravity Separation	Separation	1,2,3,4,5	Liquid
Ozonation	Destruction	3,4	Liquid, Gas
Solvent Extraction	Separation	3,4,5	Liquid, Solid
Technologies Limited by the Presence of Metals:			
Biological Treatment**	Destruction	3,5	Liquid, Solid
Carbon Adsorption**	Separation	3,4	Liquid, Gas
Technologies with Questionable Applicability or In Early Stages of Development:			
Chemical Oxidation***	Destruction	3,4,5	Liquid, Solid
Cross-Flow*** Evaporation	Separation	3,4	Liquid
Dehalogenation***	Destruction	3,4	Liquid
Hydrolysis***	Destruction	3,4	Liquid
Photocatalytic Oxidation***	Destruction	3,4,5	Liquid
Pyrolysis***	Destruction/ Separation	1,2,3,4,5	Solid, Liquid
Supercritical Extraction***	Separation	3,4,5	Liquid, Solid
Supercritical Oxidation***	Destruction	3,4,5	Liquid, Gas
Wet Air Oxidation***	Destruction	3,4,5	Liquid

* Waste Types:(1) inorganics without heavy metals; (2) inorganics with heavy metals; (3) organics without heavy metals; (4) organics with heavy metals; and (5) oil/water.

** These Technologies are sensitive to metal contaminants. Metals that are present in concentrations of a few mg/l (or mg/kg) may adversely affect treatment performance.

Table 2: Cost of Alternative Treatment Technologies

Technology	Cost	Typically Built Onsite	Form of Waste
Air Stripping	$0.29 to $0.66 per 1,000 gals**	Yes	Liquid
Biological Treatment	$33 per ton	Yes	Soil*
Carbon Adsorption	$56 per 1,000 gallons**	Yes	Liquid
Chemical Oxidation	$0.25 to $17 per 1,000 gallons	Yes	Liquid
Cross-Flow Evaporation	Competitive with Air stripping and Carbon Adsorption	Yes	Liquid
Dehalogenation	$67 to $200 per ton	No	Soil*
Distillation	$70 to $380 per ton**	No	Solid, Sludge
Gravity Separation	$27 to $207 per ton**	Yes	Liquid
Hydrolysis	$73 per ton	No	Soil*, Sludge, Solids, Electroplating Waste
	$24 to $90 per ton	No	Soil*
Ozonation	$0.25 to $17 per 1,000 gallons	Yes	Liquid
	$30 to $175 per ton	No	Soil*
Photocatalytic Oxidation	$1 to $2 per 1,000 gallons	No	Liquid
Pyrolysis	$300 to $1,400 per ton**	No	Solid, Ground Water, Sludge, Soil*
	$3,200 per ton**	No	Soil*
Solvent Extraction	$120 to $450 per ton**	Yes	Solid
	$18 per 1,000 gallons**	Yes	Liquid
Supercritical Extraction	$15 per 1,000 gallons**	No	Liquid
Supercritical Oxidation	$24 to $75 per ton	No	Solid
Wet Air Oxidation	$60 to $70 per 1,000 gallons	No	Liquid

* Database cost information was given for only soil. While soil wastes are typically derived during one-time remediation and are not routine wastestreams, these costs are listed because they were the only data available.
** Includes costs of incineration of separated liquid/hazardous residual stream.

Table 3 : Quantity of Key Wastestreams That Could Be Managed By Each of the Alternative Technologies

Wastestream (Form and Source)	Applicable Alternative Technologies	Quantity That Could Be Managed (Tons)	Costs Ranges for Alternatives
Wastewaters and Aqueous Wastes (PF06) from Process Waste Removal and Cleaning (S07)	1,2,3,4,6, 7,9,10,13, 14	275,140	\$0.25 to \$70/1000 gal.
Wastewaters and Aqueous Wastes (PF06) From Solvent & Product/ Recovery/ Distillation (S05)	1-10,13, 14,16	247,428	\$0.25 to \$70/1000 gal.
Wastewaters and Aqueous Wastes (PF06) From Product Processing (S06)	1-10,13,14	229,036	\$0.25 to \$70/1000 gal.
Nonhalogenated Solvents & Other Organic Liquids (PF02) From Process Waste Removal & Cleaning (S07)	4,6,7,9, 12,16	222,329	\$0.25 to \$17/1000 gal. \$24 to \$3,200/ton
Nonhalogenated Solvents & Other Organic Liquids (PF02) From Solvent & Product/Recovery/Distillation (S05)	9,12,16	219,892	\$15 to \$18/1000 gal. \$120 to \$3,200/ton
Still Bottoms (PF03) From Pollution Control & Wastewater Treatment (S13)	4,6,7,8, 9,11,12, 15,16	180,282	\$0.25 to \$17/1000 gal. \$115 to \$3,200/ton
Wastewater Treatment Sludges (PF07) From Pollution Control Wastewater Treatment (S13)	2,4,8,10, 11,12,15, 16	112,924	\$0.25 to \$70/1000 gal. \$24 to \$3,200/ton
Halogenated Organics/ Solvents (PF01) from Pollution Control & Wastewater Treatment (S13)	1,3,5,6, 7,9,12, 14,16	98,939	\$0.25 to \$56/1000 gal. \$30 to \$3,200/ton

Codes for Applicable Alternative Technologies: (1) Air Stripping; (2) Biological Treatment; (3) Carbon Adsorption; (4) Chemical Oxidation; (5) Dehalogenation; (6) Distillation; (7) Gravity Separation; (8) Supercritical Oxidation; (9) Solvent Extraction; (10) Wet Air Oxidation; (11) Hydrolysis; (12) Pyrolysis;(13) Cross-Flow Evaporation; (14) Ozonation; (15) Photocatalytic Oxidation; and (16) Supercritical Extraction.

APPENDIX A

FORM CODE/SOURCE CODE DESCRIPTIONS

Form Code/Source Code Descriptions

Form Code	Description
PF01	Halogenated Organic / Solvents
PF02	Nonhalogenated Solvents & Other Organic Liquids
PF03	Still Bottoms
PF04	Oily Wastes
PF05	Paint, Ink, Polymers, Resins & Coating Wastes
PF06	Wastewaters and Aqueous Waste
PF07	Wastewater Treatment Sludges
PF08	Soil, Sediment, Lagoon Sludges & Drilling Muds
PF09	Ash and Solid Thermal Residues
PF10	Other Inorganic Sludges, Brines & Solids
PF11	Cyanide Wastes & Plating Sludges
PF12	Sulfide and Reactive Wastes
PF13	Acids and Caustics
PF14	Lab Packs, Concentrated Chemicals & Containers
PF15	Scrap Metals, Drums, and Batteries
PF16	Adsorbents, Filters and Spent Carbon
PF17	Liquid Mercury
PF18	Wastes Containing Asbestos
PF19	Gases
PF20	Unknown or Blank

Source Code	Description
S01	Cleaning, Rinsing and Degreasing
S02	Painting and Coating
S03	Plating and Etching
S04	Metal Treatment and Forming
S05	Solvent & Product/Recovery / Distillation
S06	Product Processing
S07	Process Waste Removal and Cleaning
S08	Waste and Spent Material Removal
S09	Laboratory Operations
S10	Discarding and Decommissioning
S11	Routine Spill & Leak Collection
S12	Remediation and Closure
S13	Pollution Control & Wastewater Treatment
S14	Unknown

APPENDIX B

BRS DATA REVIEWED FOR THIS REPORT

ord ber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
1	PF20	Unknown or blank	S14	Unknown	1,236	317,460
2	PF06	Wastewaters and aqueous wastes	S07	Process waste removal and cleaning	41	275,140
3	PF06	Wastewaters and aqueous wastes	S05	Solvent & product/recovery/distillation	16	247,428
4	PF06	Wastewaters and aqueous wastes	S06	Product processing	31	229,036
5	PF02	Nonhalogenated solvents & other organic liquids	S07	Process waste removal and cleaning	132	222,329
6	PF02	Nonhalogenated solvents & other organic liquids	S05	Solvent & product/recovery/distillation	84	219,892
7	PF01	Halogenated organics/solvents	S14	Unknown	692	200,019
8	PF03	Still bottoms	S13	Pollution control & wastewater treatment	4	130,282
9	PF07	Wastewater treatment sludges	S13	Pollution control & wastewater treatment	14	112,924
10	PF02	Nonhalogenated solvents & other organic liquids	S14	Unknown	704	109,734
11	PF01	Halogenated organics/solvents	S13	Pollution control & wastewater treatment	30	98,939
12	PF04	Oily wastes	S14	Unknown	592	94,421
13	PF02	Nonhalogenated solvents & other organic liquids	S06	Product processing	104	92,869
14	PF14	Lab packs, concentrated chemicals & containers	S14	Unknown	1,791	88,790
15	PF02	Nonhalogenated solvents & other organic liquids	S13	Pollution control & wastewater treatment	25	63,101
16	PF04	Oily wastes	S08	Waste and spent material removal	114	37,840
17	PF03	Still bottoms	S05	Solvent & product/recovery/distillation	22	37,331
18	PF01	Halogenated organics/solvents	S06	Product processing	39	34,041
19	PF01	Halogenated organics/solvents	S07	Process waste removal and cleaning	85	32,473
20	PF05	Paint, ink, polymers, resins & coating wastes	S06	Product processing	41	26,459
21	PF04	Oily wastes	S13	Pollution control & wastewater treatment	18	26,376
22	PF05	Paint, ink, polymers, resins & coating wastes	S14	Unknown	361	25,931
23	PF01	Halogenated organics/solvents	S05	Solvent & product/recovery/distillation	29	21,175
24	PF06	Wastewaters and aqueous wastes	S14	Unknown	209	20,015
25	PF04	Oily wastes	S05	Solvent & product/recovery/distillation	3	17,377
26	PF05	Paint, ink, polymers, resins & coating wastes	S05	Solvent & product/recovery/distillation	24	17,226
27	PF08	Soil, sediment, lagoon sludges, & drilling muds	S12	Remediation and closure	11	12,938
28	B489		S13	Pollution control & wastewater treatment	1	12,753
29	PF04	Oily wastes	S07	Process waste removal and cleaning	22	12,110
30	PF14	Lab packs, concentrated chemicals & containers	S05	Solvent & product/recovery/distillation	30	11,927
31	PF06	Wastewaters and aqueous wastes	S11	Routine spill & leak collection	19	11,151
				Total	6,524	2,859,486

Order Number	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
32	PF04	Oily wastes	S12	Remediation and closure	12	10,393
33	PF05	Paint, ink, polymers, resins & coating wastes	S07	Process waste removal and cleaning	61	10,156
34	PF20	Unknown or blank	S06	Product processing	57	8,681
35	PF06	Wastewaters and aqueous wastes	S13	Pollution control & wastewater treatment	15	7,678
36	PF01	Halogenated organics/solvents	S01	Cleaning, rinsing and degreasing	103	7,604
37	PF20	Unknown or blank	S12	Remediation and closure	27	7,598
38	PF12	Sulfide and reactive wastes	S06	Product processing	4	7,485
39	PF20	Unknown or blank	S13	Pollution control & wastewater treatment	80	6,997
40	B494		S14	Unknown	1	6,435
41	PF08	Soil, sediment, lagoon sludges, & drilling muds	S14	Unknown	152	6,293
42	PF02	Nonhalogenated solvents & other organic liquids	S01	Cleaning, rinsing and degreasing	82	6,238
43	PF02	Nonhalogenated solvents & other organic liquids	S08	Waste and spent material removal	15	6,183
44	PF04	Oily wastes	S11	Routine spill & leak collection	12	6,072
45	PF05	Paint, ink, polymers, resins & coating wastes	S10	Discarding and decommissioning	90	5,748
46	PF14	Lab packs, concentrated chemicals & containers	S12	Remediation and closure	87	5,708
47	PF20	Unknown or blank	S10	Discarding and decommissioning	70	5,556
48	PF05	Paint, ink, polymers, resins & coating wastes	S11	Routine spill & leak collection	22	5,164
49	PF16	Adsorbents, filters and spent carbon	S14	Unknown	232	5,018
50	PF05	Paint, ink, polymers, resins & coating wastes	S08	Waste and spent material removal	30	4,936
51	PF14	Lab packs, concentrated chemicals & containers	S06	Product processing	108	4,015
52	PF14	Lab packs, concentrated chemicals & containers	S07	Process waste removal and cleaning	181	3,815
53	PF20	Unknown or blank	S08	Waste and spent material removal	38	3,394
54	PF14	Lab packs, concentrated chemicals & containers	S01	Cleaning, rinsing and degreasing	127	3,219
55	PF02	Nonhalogenated solvents & other organic liquids	S10	Discarding and decommissioning	97	3,028
56	PF20	Unknown or blank	S05	Solvent & product/recovery/distillation	20	2,979
57	PF08	Soil, sediment, lagoon sludges, & drilling muds	A66		1	2,900
58	PF06	Wastewaters and aqueous wastes	S12	Remediation and closure	12	2,891
59	PF06	Wastewaters and aqueous wastes	S01	Cleaning, rinsing and degreasing	30	2,768
60	PF05	Paint, ink, polymers, resins & coating wastes	S13	Pollution control & wastewater treatment	15	2,729
61	B597		S08	Waste and spent material removal	1	2,259
62	PF14	Lab packs, concentrated chemicals & containers	S10	Discarding and decommissioning	378	2,235
63	PF02	Nonhalogenated solvents & other organic liquids	S02	Painting and coating	49	2,194
				Total	8,733	3,027,857

ord ber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
64	PF14	Lab packs, concentrated chemicals & containers	S13	Pollution control & wastewater treatment	92	2,136
65	PF14	Lab packs, concentrated chemicals & containers	S02	Painting and coating	194	2,103
66	PF20	Unknown or blank	S07	Process waste removal and cleaning	54	2,097
67	PF03	Still bottoms	S14	Unknown	49	2,092
68	PF15	Scrap metals, drums, and batteries	S14	Unknown	37	1,889
69	PF10	Other inorganic sludges, brines & solids	S08	Waste and spent material removal	16	1,591
70	PF01	Halogenated organics/solvents	S09	Laboratory operations	67	1,570
71	PF07	Wastewater treatment sludges	S08	Waste and spent material removal	2	1,562
72	PF07	Wastewater treatment sludges	S14	Unknown	25	1,518
73	PF14	Lab packs, concentrated chemicals & containers	S09	Laboratory operations	251	1,425
74	PF10	Other inorganic sludges, brines & solids	S14	Unknown	45	1,394
75	PF08	Soil, sediment, lagoon sludges, & drilling muds	S11	Routine spill & leak collection	34	1,370
76	PF16	Adsorbents, filters and spent carbon	S06	Product processing	39	1,329
77	PF20	Unknown or blank	S01	Cleaning, rinsing and degreasing	53	1,287
78	PF04	Oily wastes	S06	Product processing	11	1,268
79	PF05	Paint, ink, polymers, resins & coating wastes	S02	Painting and coating	81	1,265
80	PF14	Lab packs, concentrated chemicals & containers	S11	Routine spill & leak collection	152	1,246
81	PF02	Nonhalogenated solvents & other organic liquids	S09	Laboratory operations	63	1,192
82	PF03	Still bottoms	S07	Process waste removal and cleaning	6	930
83	PF01	Halogenated organics/solvents	S10	Discarding and decommissioning	79	927
84	PF04	Oily wastes	S01	Cleaning, rinsing and degreasing	10	910
85	PF14	Lab packs, concentrated chemicals & containers	S08	Waste and spent material removal	117	885
86	PF20	Unknown or blank	S11	Routine spill & leak collection	43	865
87	PF20	Unknown or blank	S02	Painting and coating	70	783
88	PF06	Wastewaters and aqueous wastes	S08	Waste and spent material removal	4	776
89	PF02	Nonhalogenated solvents & other organic liquids	S11	Routine spill & leak collection	15	544
90	PF12	Sulfide and reactive wastes	S07	Process waste removal and cleaning	4	498
91	PF06	Wastewaters and aqueous wastes	S10	Discarding and decommissioning	41	483
92	PF19	Gases	S13	Pollution control & wastewater treatment	5	465
93	PF13	Acids and caustics	S13	Pollution control & wastewater treatment	4	440
94	PF08	Soil, sediment, lagoon sludges, & drilling muds	S07	Process waste removal and cleaning	12	418
95	PF01	Halogenated organics/solvents	S08	Waste and spent material removal	26	381
				Total	10,434	3,065,498

ord umber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
96	PF16	Adsorbents, filters and spent carbon	S08	Waste and spent material removal	37	370
97	PF01	Halogenated organics/solvents	S11	Routine spill & leak collection	9	368
98	PF16	Adsorbents, filters and spent carbon	S13	Pollution control & wastewater treatment	23	324
99	PF08	Soil, sediment, lagoon sludges, & drilling muds	S08	Waste and spent material removal	9	300
100	PF20	Unknown or blank	S09	Laboratory operations	30	294
101	PF04	Oily wastes	S04	Metal treatment and forming	3	286
102	PF04	Oily wastes	A66		1	285
103	PF03	Still bottoms	S08	Waste and spent material removal	8	283
104	PF02	Nonhalogenated solvents & other organic liquids	S12	Remediation and closure	14	276
105	PF11	Cyanide wastes and plating sludges	S14	Unknown	42	274
106	PF05	Paint, ink, polymers, resins & coating wastes	S01	Cleaning, rinsing and degreasing	40	258
107	PF10	Other inorganic sludges, brines & solids	S07	Process waste removal and cleaning	6	250
108	PF10	Other inorganic sludges, brines & solids	S06	Product processing	6	241
109	PF16	Adsorbents, filters and spent carbon	S02	Painting and coating	36	235
110	PF04	Oily wastes	S10	Discarding and decommissioning	13	228
111	PF16	Adsorbents, filters and spent carbon	S07	Process waste removal and cleaning	19	222
112	PF01	Halogenated organics/solvents	S12	Remediation and closure	26	222
113	PF16	Adsorbents, filters and spent carbon	S10	Discarding and decommissioning	20	221
114	PF08	Soil, sediment, lagoon sludges, & drilling muds	S06	Product processing	8	214
115	PF09	Ash and solid thermal residues	S13	Pollution control & wastewater treatment	6	209
116	PF08	Soil, sediment, lagoon sludges, & drilling muds	S13	Pollution control & wastewater treatment	9	206
117	PF03	Still bottoms	S06	Product processing	3	199
118	PF03	Still bottoms	S01	Cleaning, rinsing and degreasing	8	198
119	PF13	Acids and caustics	S14	Unknown	36	193
120	PF12	Sulfide and reactive wastes	S01	Cleaning, rinsing and degreasing	3	162
121	PF09	Ash and solid thermal residues	S01	Cleaning, rinsing and degreasing	1	158
122	B043		S06	Product processing	1	154
123	PF13	Acids and caustics	S06	Product processing	1	142
124	PF06	Wastewaters and aqueous wastes	S02	Painting and coating	4	136
125	PF12	Sulfide and reactive wastes	S14	Unknown	30	132
126	PF14	Lab packs, concentrated chemicals & containers	S03	Painting and etching	29	120
127	PF10	Other inorganic sludges, brines & solids	S13	Pollution control & wastewater treatment	6	114
				Total	10,921	3,072,772

ord mber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
128	PF06	Wastewaters and aqueous wastes	S09	Laboratory operations	18	109
129	PF03	Still bottoms	S10	Discarding and decommissioning	4	103
130	PF16	Adsorbents, filters and spent carbon	S11	Routine spill & leak collection	30	95
131	PF05	Paint, ink, polymers, resins & coating wastes	S09	Laboratory operations	17	92
132	PF14	Lab packs, concentrated chemicals & containers	A66		3	83
133	PF11	Cyanide wastes and plating sludges	S01	Cleaning, rinsing and degreasing	2	78
134	PF16	Adsorbents, filters and spent carbon	S01	Cleaning, rinsing and degreasing	15	76
135	PF12	Sulfide and reactive wastes	S04	Metal treatment and forming	2	73
136	PF13	Acids and caustics	S03	Painting and etching	3	73
137	PF11	Cyanide wastes and plating sludges	S06	Product processing	3	66
138	PF01	Halogenated organics/solvents	S02	Painting and coating	37	65
139	PF10	Other inorganic sludges, brines & solids	S12	Remediation and closure	3	60
140	B498		S06	Product processing	1	58
141	PF19	Gases	S14	Unknown	27	57
142	PF13	Acids and caustics	S01	Cleaning, rinsing and degreasing	7	54
143	PF04	Oily wastes	S09	Laboratory operations	3	46
144	PF19	Gases	S10	Discarding and decommissioning	8	43
145	PF16	Adsorbents, filters and spent carbon	S12	Remediation and closure	8	41
146	PF07	Wastewater treatment sludges	S06	Product processing	1	38
147	PF14	Lab packs, concentrated chemicals & containers	S04	Metal treatment and forming	11	34
148	PF15	Scrap metals, drums, and batteries	S10	Discarding and decommissioning	11	34
149	B489		S11	Routine spill & leak collection	1	30
150	PF11	Cyanide wastes and plating sludges	S03	Painting and etching	11	30
151	PF08	Soil, sediment, lagoon sludges, & drilling muds	S10	Discarding and decommissioning	9	30
152	PF06	Wastewaters and aqueous wastes	S03	Painting and etching	5	29
153	PF09	Ash and solid thermal residues	S14	Unknown	6	26
154	PF10	Other inorganic sludges, brines & solids	S02	Painting and coating	1	25
155	PF03	Still bottoms	S11	Routine spill & leak collection	2	24
156	PF15	Scrap metals, drums, and batteries	S11	Routine spill & leak collection	3	22
157	PF15	Scrap metals, drums, and batteries	S06	Product processing	5	22
158	PF07	Wastewater treatment sludges	S12	Remediation and closure	2	20
159	PF04	Oily wastes	A14		1	20
				Total	11,181	3,074,433

cord mber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
160	PF16	Adsorbents, filters and spent carbon	S03	Painting and etching	20	18
161	PF13	Acids and caustics	S10	Discarding and decommissioning	7	17
162	PF18	Wastes containing asbestos	S07	Process waste removal and cleaning	1	16
163	PF08	Soil, sediment, lagoon sludges, & drilling muds	S02	Painting and coating	1	16
164	PF12	Sulfide and reactive wastes	S11	Routine spill & leak collection	1	14
165	PF16	Adsorbents, filters and spent carbon	S09	Laboratory operations	8	14
166	PF01	Halogenated organics/solvents	A66		1	14
167	PF12	Sulfide and reactive wastes	S13	Pollution control & wastewater treatment	3	14
168	PF05	Paint, ink, polymers, resins & coating wastes	S12	Remediation and closure	6	13
169	PF13	Acids and caustics	S07	Process waste removal and cleaning	5	13
170	PF12	Sulfide and reactive wastes	S10	Discarding and decommissioning	10	13
171	PF16	Adsorbents, filters and spent carbon	S05	Solvent & product/recovery/distillation	4	13
172	PF09	Ash and solid thermal residues	S07	Process waste removal and cleaning	1	13
173	PF16	Adsorbents, filters and spent carbon	S04	Metal treatment and forming	2	12
174	PF20	Unknown or blank	S03	Painting and etching	6	11
175	PF10	Other inorganic sludges, brines & solids	S11	Routine spill & leak collection	4	11
176	PF19	Gases	S02	Painting and coating	16	10
177	PF10	Other inorganic sludges, brines & solids	S10	Discarding and decommissioning	3	10
178	PF04	Oily wastes	S02	Painting and coating	1	10
179	PF19	Gases	S09	Laboratory operations	5	9
180	PF15	Scrap metals, drums, and batteries	S09	Laboratory operations	3	8
181	PF15	Scrap metals, drums, and batteries	S02	Painting and coating	3	7
182	PF11	Cyanide wastes and plating sludges	S07	Process waste removal and cleaning	3	5
183	PF02	Nonhalogenated solvents & other organic liquids	S03	Painting and etching	4	5
184	PF15	Scrap metals, drums, and batteries	S01	Cleaning, rinsing and degreasing	2	4
185	PF09	Ash and solid thermal residues	S06	Product processing	1	4
186	PF09	Ash and solid thermal residues	S11	Routine spill & leak collection	1	4
187	PF08	Soil, sediment, lagoon sludges, & drilling muds	S01	Cleaning, rinsing and degreasing	2	4
188	PF14	Lab packs, concentrated chemicals & containers	A81		1	4
189	PF15	Scrap metals, drums, and batteries	S08	Waste and spent material removal	8	4
190	PF10	Other inorganic sludges, brines & solids	S09	Laboratory operations	3	4
191	PF13	Acids and caustics	S09	Laboratory operations	6	3
				Total	11,323	3,074,750

?ord ?mber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
192	PF20	Unknown or blank	S04	Metal treatment and forming	4	3
193	PF11	Cyanide wastes and plating sludges	S10	Discarding and decommissioning	8	3
194	PF11	Cyanide wastes and plating sludges	S13	Pollution control & wastewater treatment	3	3
195	B393		S08	Waste and spent material removal	1	3
196	PF15	Scrap metals, drums, and batteries	S07	Process waste removal and cleaning	4	2
197	PF10	Other inorganic sludges, brines & solids	S01	Cleaning, rinsing and degreasing	2	2
198	PF05	Paint, ink, polymers, resins & coating wastes	S03	Painting and etching	7	2
199	PF05	Paint, ink, polymers, resins & coating wastes	S04	Metal treatment and forming	4	2
200	PF06	Wastewaters and aqueous wastes	S04	Metal treatment and forming	2	2
201	PF11	Cyanide wastes and plating sludges	S12	Remediation and closure	2	2
202	PF19	Gases	S07	Process waste removal and cleaning	3	1
203	PF15	Scrap metals, drums, and batteries	S12	Remediation and closure	2	1
204	PF01	Halogenated organics/solvents	S03	Painting and etching	3	1
205	PF03	Still bottoms	S09	Laboratory operations	1	1
206	PF11	Cyanide wastes and plating sludges	S08	Waste and spent material removal	4	1
207	PF01	Halogenated organics/solvents	S04	Metal treatment and forming	1	1
208	PF07	Wastewater treatment sludges	S10	Discarding and decommissioning	2	1
209	PF03	Still bottoms	S02	Painting and coating	1	1
210	PF19	Gases	S06	Product processing	1	1
211	PF12	Sulfide and reactive wastes	S08	Waste and spent material removal	1	1
212	PF17	Liquid mercury	S14	Unknown	1	1
213	PF08	Soil, sediment, lagoon sludges, & drilling muds	S09	Laboratory operations	2	1
214	PF11	Cyanide wastes and plating sludges	S09	Laboratory operations	1	1
215	PF17	Liquid mercury	S13	Pollution control & wastewater treatment	1	1
216	PF09	Ash and solid thermal residues	S09	Laboratory operations	1	1
217	PF03	Still bottoms	A18		1	0
218	PF15	Scrap metals, drums, and batteries	S13	Pollution control & wastewater treatment	1	0
219	PF12	Sulfide and reactive wastes	S09	Laboratory operations	1	0
220	PF19	Gases	S01	Cleaning, rinsing and degreasing	2	0
221	PF19	Gases	S08	Waste and spent material removal	1	0
222	PF07	Wastewater treatment sludges	S04	Metal treatment and forming	1	0
223	PF11	Cyanide wastes and plating sludges	S04	Metal treatment and forming	1	0
				Total	11,393	3,074,789

ord mber	Form Code Groupings	Description of Form Code Groupings	Source Code Groupings	Description of Source Code Groupings	Number of Generators	Quantity of Waste Burned
224	PF13	Acids and caustics	S11	Routine spill & leak collection	1	0
225	PF02	Nonhalogenated solvents & other organic liquids	S04	Metal treatment and forming	1	0
226	PF20	Unknown or blank	A82		1	0
227	PF19	Gases	S11	Routine spill & leak collection	1	0
228	PF13	Acids and caustics	S12	Remediation and closure	1	0
229	PF19	Gases	S04	Metal treatment and forming	1	0
230	PF09	Ash and solid thermal residues	S10	Discarding and decommissioning	1	0
				Total	11,400	3,074,789

APPENDIX C

TECHNOLOGIES THAT CAN BE USED FOR ALTERNATIVE TREATMENTS OF SUBJECT WASTES THAT ARE CURRENTLY INCINERATED

AIR STRIPPING

Air stripping is a mass-transfer process used to move volatile contaminants from water to air. Temperature, pressure, air-water flow rate ratio, and available surface area are important parameters in the design of air strippers. The process is effective for aqueous wastestreams with low concentrations of organic constituents that are highly volatile and have relatively low water solubility. Off-gases must usually be treated to recapture and/or destroy contaminants.

Additional Information and Costs

Information in the Alternative Treatment Technology Information Center (ATTIC) indicated that this technology is applicable for the treatment of volatile organic compounds (VOCs) in the following media: air, soil, ground water, and water. Cost data were only provided for two entries. Treatment costs were estimated at between $0.29 and $0.66 per 1,000 gallons of groundwater.

BIOLOGICAL TREATMENT

Biological treatment is a technology applicable to wastewaters and some solids containing biodegradable organic constituents. Biological treatment can be one of various types; some of these include: activated sludge, aerated lagoon, anaerobic digestion, anaerobic filtration, trickling filters, stabilization ponds, rotating biological contactor, biological seeding, composting, and enzymatic treatment. Biological treatment can be either aerobic (in the presence of oxygen) or anaerobic (without oxygen). The basic principle of operation for aerobic biological treatment is that living, oxygen-requiring micro-organisms decompose organic constituents into carbon dioxide, water, nitrates, sulfates, simpler low-molecular-weight organic by-products, and cellular biomass. In anaerobic biological treatment, micro-organisms typically transform organic constituents into carbon dioxide and methane gas.

Additional Information and Costs

Information in ATTIC related to biological treatment indicated that the technology is applicable for the treatment of pentachlorophenol (PCP) in surface soil at a cost of $33 per ton.

Information from Hazardous Waste Treatment Technologies, 1991 gives the following cost estimates for biological treatment (for flow rate less than 0.1 mgd). Capital costs range from $0.76 million for the trickling filter process to $1.14 million for the rotating biological contactor. The highest and lowest annual operating costs are also found to be the rotating biological contactor process ($0.153 million) and the trickling filter process ($0.103 million) respectively.

CARBON ADSORPTION

Carbon adsorption is a treatment technology used to treat wastewaters containing dissolved organics at concentrations less than approximately 5 percent and, to a lesser extent, dissolved metals and other inorganic contaminants. The process of adsorption involves the adherence of organic constituents to the surface of the activated carbon by physical and chemical processes. The two most common carbon adsorption processes are the granular activated carbon (GAC), which is used in packed beds, and powdered activated carbon, which is added loosely to wastewater. After the activated carbon is saturated, it is either regenerated or incinerated. In regeneration, the organics are released and must be incinerated or recovered.

Additional Information and Costs

Information in ATTIC indicated that this technology was applicable for the treatment of dioxins, furans, polychlorinated biphenyls (PCBs), pentachlorophenol (PCP), halogenated volatiles, halogenated semi-volatiles, pesticide phosphate esters, and TCDD (dioxin) in soil. From the available information, treatment costs were estimated at $56 per 1,000 gallons of wastewater (including incineration of spent carbon).

Information from Chemical Engineering Process, April, 1993 shows the following for typical **uninstalled** capital costs for carbon adsorption systems (with two adsorbers per system): for 2,000 lb capacity per adsorber, with a 60 gal/min flow rate, $50,000; for 10,000 lb capacity per absorber, with a 250 gal/min flow rate, $110,000; for 20,000 lb capacity per absorber, with a 500 gal/min flow rate, $165,000.

The Standard Handbook of Hazardous Waste Treatment and Disposal, 1989 states that generic cost prediction is difficult to construct since the difference between systems will radically affect the cost. Capital costs for fixed-bed systems are typically a function of wastewater flowrate. Costs include site preparation, foundations, building, feed and backwash pumps, air compressor, electrical components, automatic controls, engineering, overhaul, and profit. Operating costs are relatively minor for small, well behaved systems, consisting primarily of power (approximately $15,000 per year for a 1 mgd system) and labor (2 to 3 checks per shift). The cost of incinerating spent carbon is not given.

CHEMICAL OXIDATION

Chemical oxidation is a destruction technology used to treat waste containing organics. The basic principle of operation for chemical oxidation involves oxidation reactions to yield carbon dioxide and water, salts, and simple organic acids. The principle oxidants used are hypochlorite, chlorine gas, chlorine dioxide, hydrogen peroxide, ozone, and potassium permanganate.

Additional Information and Costs

For chemical oxidation, the ATTIC data base provided only capital costs for constructing a treatment system. These estimates are of project costs, rather than purely treatment costs, and are provided with that caveat. The projected capital cost was $70,000 to $260,000. The costs for treating aqueous wastes ranged from $0.25 to over $17 per 1,000 gallons.

CROSS-FLOW EVAPORATION

Cross-flow membrane evaporation is designed to removed VOCs from contaminated water. VOCs diffuse from the membrane and are drawn under vacuum. Upstream of the vacuum pump, a condenser traps the vapors and condenses the organic vapors to contain fugitive emissions. This process has been used on industrial process waste and used to recover solvents for reuse.

Additional Information and Costs

Specific cost information was not available. However, costs were stated to be competitive with air stripping and carbon adsorption.

DEHALOGENATION

Dehalogenation is a process designed to detoxify or destroy liquid halogenated wastes by detaching halogenated atoms from the carbon atoms in the waste and replacing them with other atoms, such as hydrogen. Alkali metal/polyethylene glycol (APEG) dehalogenation is used to remove halogens from chlorinated organics.

Additional Information and Costs

Information in ATTIC pertaining to treatment cost for dehalogenation indicates that treatment costs range from $67 to $200 per ton of soil. No information was found regarding the treatment of wastes other than soil.

DISTILLATION

Distillation is a thermal treatment technology applicable to the treatment of wastes containing organics that are volatile enough to be removed by the application of heat. The four most common distillation technologies include batch distillation, fractionation, steam stripping, and thin film evaporation.

Additional Information and Costs

Information in the ATTIC data base shows that the costs range from $70 to $380 per ton for sludges. It is noted in ATTIC that the cost of thermal distillation treatment as applied to refinery wastes is greatly dependent on the capacity of the processing system. The range between high and low treatment costs at a given capacity reflects site-specific factors such as waste composition, mobile or fixed facility, and unique operating concerns.

Information from the Standard Handbook of Hazardous Waste Treatment and Disposal, 1989 state that capital costs can vary depending on the design variables, such as the size and type of reboiler, column height, column diameter, column intervals, degree of automation, and materials of construction. One particular system designed for ethanol recovery from an aqueous wastestream show the following for costs: System equipment cost is $1,050,000; Total annual cost $336,300; Cost per unit volume of aqueous waste processed was $0.0025/L ($0.0095/gal). Cost per unit volume of ethanol re-covered was $0.084/L ($0.318/gal).

GRAVITY SEPARATION

Gravity separation is a process used primarily to treat two-phased aqueous wastes such as oil in water. For efficient separation, the nonaqueous phase should have a significantly different specific gravity than water and should be present as a nonemulsified substance.

Emulsion between water and oil is common, and an emulsion breaking chemical must be added to this type of waste prior to treatment.

Additional Information and Costs

Information in the ATTIC data base shows that the costs for gravity separation range from $27 to $207 per ton of liquid.

HYDROLYSIS

Hydrolysis is a technology that causes decomposition of a chemical compound. Typically, during hydrolysis, a chemical reaction occurs in which water reacts with another substance to form two or more new substances. Elevated temperatures and/or pressures usually enhance rates of hydrolysis. Hydrolysis will replace one or more halogen groups with hydroxyl groups. The resulting compound is generally more oxidizable or biodegradable. The process is primarily used to treat aqueous wastes containing refractory organics.

Additional Information and Costs

Information in ATTIC indicated that this technology is applicable for the treatment of heavy metals, high molecular weight organics, aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc in soil, sludge, solids, and electroplating wastes. From the available information, treatment costs were estimated at $73 per ton of raw waste treated, excluding the costs of waste excavation, curing, and storage and final placement or disposal of the treated waste. According to information in ATTIC, the total cost of treatment depends on the rate of processing, the need to pretreat wastes, and costs associated with placement or disposal of treated waste.

ATTIC also provided information on the treatment of volatile hydrophilic organic compounds, volatile hydrophobic organic compounds, nonvolatile hydrophilic organic compounds, nonvolatile hydrophobic organic compounds, VOCs, PCBs, heavy metals, chlorinated hydrocarbons (CHCs), PAHC, polynuclear aromatic hydrocarbons (PAHs), bromide, cyanide, low-density hydrocarbons, crude oil, oil, mineral oil, galvanic cyanide, copper, zinc, cadmium, nickel, lead, aliphatics, aromatics, biodegradable hydrocarbons, phenol, petroleum ether extract, total cyanide, and gasoline in excavated soil. These costs ranged from $24 to $90 per ton.

OZONATION

Ozonation is a powerful oxidation process that utilizes dissolved ozone and/or hydrogen peroxide and catalysts in a controlled oxidative environment to destroy organic-laden waste. The process is specifically effective for PAHs. Some ozonation processes utilize ultraviolet radiation in conjunction with ozone to detoxify organic wastewaters. A major advantage of ozone is that it can be generated on site from air or oxygen and used immediately.

Additional Information and Costs

Information in ATTIC indicates that ozonation is suitable for the treatment of ground water, wastewater, aqueous wastes, acids, oxidizers, oils, and leachate containing halogenated solvents, phenol, pentachlorophenol (PCP), pesticides, PCBs, and other organic compounds; and soil containing PAHs. The projected capital cost of ozonation was given as $70,000 to $260,000 with operating costs of $0.25 to over $17 per 1,000 gallons of treated water. Other information in ATTIC estimated the treatment costs for soil to range from $30 to $175 per ton depending on contaminant concentrations.

Information in the Standard Handbook of Hazardous Waste Treatment and Disposal 1989, state that capital costs can vary as much as 50 percent depending on the interpretation of ozone-generator performance specifications. Major factors that must be evaluated include maximum ozone output at a specific concentration, variable ozone output at a specific concentration, auxiliary equipment (air preparation, reaction tanks), monitoring and control instrumentation, spare parts, installation costs, start-up and training, and performance warranties. Some annual budgetary costs (average prices received from several manufactures) for ozone generated from air at 1 percent ozone by weight, including air preparation but no reaction tanks are 1 pound/day (lb/d), $10,000; 5 lb/d, $22,000; 26 lb/d, $50,000; 52 lb/d, $76,000; 260 lb/d, $275,000; 520 lb/d, $680,000.

Operating costs depend primarily on the cost of electrical energy. Other factors affecting costs include electrical demand for the air dryers, ozone concentrations used, blowers and compressors, and types of injectors used. Power consumption will range from 15 to 26 watt hours/gram (Wh/g) of ozone generated (6.8 to 11.8 kilowatt hours/pound [kWh/lb] for an air feed system at 1.5 percent ozone by weight including air preparation and ozone injection.

Information from Pollution Prevention, October 1994, states that operating costs for wastewater treatment is approximately $1 to $2.5 per 1,000 gal for treatment of contaminant concentrations at 0.1 ppm; $1.5 to $4 per 1,000 gal for treatment of contaminants at concentrations of 1 ppm; and $2 to $6 for treatment of contaminants at concentrations of 10 ppm. Capital costs were stated to be a function of system size, which is a function of the UV power required to destroy the selected contaminants. The capital cost estimate given for a 82 kilowatts, Ultraviolet/ozonation system will typically range between $130,000 to $160,000.

PYROLYSIS

Pyrolysis is a technology that chemically decomposes waste by heating it in a oxygen-free environment. Volatile components are recovered or burned in a secondary chamber in the presence of oxygen. The technology may be applicable to wastes that cannot be treated effectively using conventional incineration, such as those stored in containers or having a high ash content.

Additional Information and Costs

Information in ATTIC shows that pyrolysis is applicable for the treatment of solids, ground water, sludge, and soil. The projected capital cost of plasma arc pyrolysis was given as $1.6 million, with operating costs of $300 to $1,400 per ton. Other information in ATTIC estimated the treatment costs for soil at $3,200 per ton.

PHOTOCATALYTIC OXIDATION

Photocatalytic oxidation removes and destroys dissolved organic contaminants from water in a solid state, continuous flow process at ambient temperatures. The technology uses a titanium dioxide (TIO_2) semiconductor catalyst that when excited by light, generates hydroxyl radicals that break the carbon bonds of organic wastes.

<u>Additional Information and Costs</u>

Average treatment time was 60 seconds at a direct operating cost of $1 to $2 per 1,000 gallons.

SOLVENT EXTRACTION

Solvent extraction is used to treat wastes containing a variety of organic constituents with a broad range of total organic content. The basic principle of operation in solvent extraction is that constituents are removed from a waste by mixing the waste with an extraction fluid (solvent) that will preferentially dissolve the organic waste constituents of concern from the waste. The organic waste constituents are then removed from the solvent by distillation. The solvent is then recycled.

<u>Additional Information and Costs</u>

Information in ATTIC indicates that the treatment costs range from $120 to $450 per ton. One entry for this technology provided the capital cost of constructing a treatment system and the incremental cost of waste treatment. A cost estimate was given for an extraction process to recover acetic acid from a 22,700 kg/hr (100 gpm) wastewater containing acid at 5 percent by weight. Estimated direct fixed capital was $1,030,000, with an annual operating cost of $253,000 per year or $5.90 per 1000 gallon.

Estimated operating costs (including capital charges) for solvent extraction of polar organics are approximately $18 per 1,000 gal of wastewater treated. These costs are for a conceptual system that would include an extractor, a solvent-regeneration column, a vacuum steam stripper for removal of solvent from the raffinate, and appropriate heat exchangers

Information in the <u>Standard Handbook of Hazardous Waste Treatment and Disposal</u> state that operating costs are approximately inversely proportional to the percentage of chemical in the influent. Costs data were given as ranging from $0.02 per lb of phenol recovered with a 1 percent phenol influent to $1.68 per pound with a 0.01 percent influent. Capital and operating cost estimates for a system to treat 115,000 kg/h (728,000 gallons/day) of wastewater containing 15,000 ppm of phenol are on the order of $3.3 million and $6.30 per 1,000 gal respectively.

SUPERCRITICAL EXTRACTION

Supercritical extraction is an extraction technology that involves feeding liquid or slurried solid (pumpable) waste into an extractor, contacting the waste feed with supercritical (high pressure) carbon dioxide, separating the extracted organics from the carbon dioxide by flashing (releasing the pressure), compressing the carbon dioxide, and recycling it to the extractor.

Additional Information and Costs

Information in ATTIC indicates that this technology is designed to treat 100 gpm of aqueous mixtures and is also applicable to solid surfaces. The estimated installation cost of a module is $50,000, with a long-term cost of $15 per 1,000 gallons. PCB cleanups, solvent spills, and oil-contaminated beach sands were given as treatment technology targets.

SUPERCRITICAL OXIDATION

Supercritical water oxidation is a destructive process for organic contaminants in liquid or solid wastestreams. The process involves using an oxidant in water at temperatures and pressures above the critical point of water, 705°F and 3,208 psi. Water maintained above these levels assumes a supercritical form, its liquid and vapor densities converge, and the two phases become indistinguishable.

Additional Information and Costs

Information in ATTIC shows that treatment costs for supercritical oxidation range from $24 to $75 per ton.

WET AIR OXIDATION

Wet air oxidation involves heating an aqueous wastestream and compressed air and passing the stream through a high pressure reactor to oxidize dissolved organics. The process is designed principally to treat wastestreams containing less than 5 percent organics. Aromatic halogenated organics, such as PCBs are usually too stable to be destroyed by the process. Further, the process is not applicable to solids, viscous liquids, and relatively large volume wastes.

Additional Information and Costs

Information in ATTIC indicates that wet air oxidation is suitable for the treatment of halogenated organics, inorganic/organic sludges, contaminated groundwater, inorganic/organic cyanides, phenols, and leachates. The projected capital cost was $1.5 million, with treatment costs of $60 to $70 cents per 1,000 gallons.

NOTE TO ELECTRONIC FILE USERS:

APPENDIX CONTINUES ON SEPARATE FILES. SEE NOTE ON PAGE 1.