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Project Summary

PCB Sediment Decontamination—Technical/Economic Assessment of Selected Alternative Treatments

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Eleven emerging alternative treatments for Polychlorinated Biphenyl (PCB) contaminated sediments have been compared and ranked using technical performance, status of development, test and evaluation data needs, and cost as factors. In ranking the processes, weights were assigned to the factors to emphasize the extent of decontamination, the estimated cost of treatment, and the versatility of the process.

The emerging treatment processes are based on six different technologies: one on low-temperature oxidation, two on chlorine removal, one on pyrolysis, three on removing and concentrating, one on vitrification, and three on microorganisms. Types of technologies not developed are chlorinolysis, stabilization, and enzymes.

On the basis of the comparisons made, the treatment processes were ranked in the following order from highest to lowest: KPEG, LARC, Acurex, Bio-Clean, Supercritical Water, Advanced Electric Reactor, Vitrification, OHM Extraction, Soilex, Composting, and Sybron Bi-Chem 1006. The first eight processes show potential for reduction of PCB concentrations to the desired background levels (1 to 5 ppm) or less, with minimum environmental impacts and low to moderate cost. All the technologies except the advanced electric reactor required further development and testing.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The PCB contamination problems in the Hudson River and New Bedford, Massachusetts are reported to be among the worst in the United States in terms of concentration and total quantity of PCBs. It is estimated that 290,000 kg of PCBs are contaminating 382,000 m^3 (500,000 yd^3) of sediments in identified "hot spots" of the Hudson River. During the 70s, approximately 907,000 kg of PCBs were used in the New Bedford area annually, of which an estimated 45,500 kg were improperly disposed. There are also numerous industrial lagoons contaminated with large quantities of PCBs. The PCB contamination problems pose threats to both drinking water and the fishing industry.

The only available proven technology is dredging and incineration. Land disposal of the sediments untreated has legal restrictions. Biodegradation is a possibility, but sufficient information does not exist to design and operate such a system. There is little experience in the application of encapsulation technology to PCB-contaminated sediments.

This study was undertaken to identify the most technically feasible processes that have been proposed by research concerns for the removal of PCBs from sediments; to identify their extent of development, effectiveness, limitations and probable costs; and to determine needs for further development. The study involved four phases: data acquisition, screening and selection of the most technically feasible processes, development of critieria for process assessment, and process assessment.

Data Acquisition

Three major source of data were: EPA's file of proposals and correspondence concerning problems of PCB contamination and possible approaches to alternative solutions; the open literature; and direct contacts with proponents of treatment technologies.

A bibliography (171 references) was prepared, which included treatment feasibility study reports, process test and evaluation reports, process development proposals, and patents. As processes were identified, direct contacts were made with the investigators for details of their process studies.

Screening and Selection of Most Technically Feasible Processes

Alternative destruction/detoxification/removal (DDR) processes were subjected to screening to identify those to be assessed further. The processes were categorized according to their generic technology so that their potential performance could be judged appropriately. Processes with undesirable aspects were rejected from further assessment. For example, lack of tolerance for water by a process is undesirable because extensive sediment drying is required. Processes showing insufficient tolerance for water were therefore rejected from further consideration as a primary treatment process in favor of more tolerant alternatives.

Table 1 lists the processes screened, identifies those selected for further assessment and gives the reasons for rejection of the rest. Some of the technologies (e.g., nucleophilic substitution) have provided several processes. Some (e.g., enzymes) have not yet provided any processes. A process evaluated as "1" in Table 1 was selected for further assessment. Other evaluation numbers assigned to the rest of the screened processes refer to footnotes that identify the reason for rejection of the process for further assessment. References cited are identified fully in the bibliography of the full report.

Development of Criteria for Process Assessment

The PCB contamination problem in the Hudson River is representative of the type of PCB destruction/detoxification problems focused on in this study. It is expected that the contaminated sediments will have to be dredged from all sites and that the dredged sediments will have high water content.

Criteria for assessment of alternative treatments were chosen which relate to a broad range of principles of operation of diverse applied technologies, yet can be used effectively in comparing one treatment process with another. Additional factors, specific to a technology, were included to help portray the inherent strengths and limitations of a process. Table 2 lists the seven criteria used in comparative process evaluation and three additional factors relating to the needs for further process development and evaluation. The table also includes an overall description of the findings for the processes evaluated.

The goal set for process performance is to reduce the PCB concentration in treated sediments to background levels of 1 to 5 ppm. Several of the processes were found to meet this goal. Those that showed reduction to less than 2 ppm were assigned a rating of "6". Those that attained a level between 2 and 10 ppm were assigned a "4". Those with residual concentrations greater than 10 ppm were rated "2".

Available capacity was found not to exist for any of the processes. However, several were developed sufficiently to permit projections of the time required to build a facility for application of the treatment. Those for which such projections could not be made were rated "2". Those requiring 24 or more months were rated "4". Those requiring 12 to 16 months were rated "6".

Conditions/limitations that were rated were tolerance for water, required processing time, and controllability of process conditions. Those treatments that could tolerate water up to about 40 percent would not require a drying step with its attendant fines' control problems. Those requiring only 1 day for treatment could generally show a faster rate of cleanup than those requiring 3 days. Some biological processes required more than 3 weeks. The treatments generally provided control of the processing conditions; however, a fe (e.g., composting) would not necessa ily do so. The three conditions/limita tions were ranked as follows:

Conditions/limitations	Ran
Tolerates to 40 percent water and treats in 1 day	6
Sediment needs to be dried	5
Tolerates to 40 percent water and treats in 3 days	4
Tolerates water and treats in >3 weeks	3
Sediment needs to be dried, treats in >3 weeks	2
Processing conditions uncontrollable	1

Concentration range handled in data developed for the processes ranged from unknown to 3,000 ppm. Ratings were assigned based on the upper limit of feed concentration. The ratings were as follows:

PCB concentration treated, ppm	Rank
≥3,000	6
2,000 to 3,000	5
1,500 to 2,000	4
500	3
250 to 350	2
Unknown	1

Status of development ratings were "1" for no data, "2" for laboratory-scale tests completed, "3" for bench-scale tests completed, "4" for pilot-scale tests completed, "5" for field tests completed; and "6" for commercial system designed and ready for construction.

Test and evaluation data needs could be rated differently, depending upon the purpose. For indicating the extent to which a treatment process is readied for use, the more data that are available the better. For indicating the need to support a very promising technology that lacks sufficient progress, the potential and the data needs should be rated in combination. The ratings used here are for the former purpose and are as follows:

Test and evaluation data needs	Rank
None except permits and checkout	6
Field tests	5
Pilot tests and costs	4
Laboratory and bench tests	3
Conceptual treatment process design	2
D/D/R data, residual PCB data, RCRA waste data	1

Table 1. *Screening of PCB Treatment Processes*

Generic technology	References	Process	Evaluation[a]
Chemical	Centofanti 1971; Chen 1982; Childs 1982; Craddock 1982; Edwards et al. 1982; Environment Canada 1983; Hornig 1984; Massey and Walsh 1985; Rogers and Kornel 1985; Rogers 1983; Rogers 1985.		
Low-temperature oxidation			
Wet air oxidation	Baillod et al. 1978; Miller and Sevientoniewski (n.d.); Miller and Fox 1982.	Uncatalyzed, general	2
		Zimpro Process, Santa Maria, CA Waste Site	4, 13
		Catalyzed	
		Dow Chemical Co. Patent 3,984,311	2
		IT Environmental Science	2
Supercritical water oxidation	Modell et al. 1982.	Modar	1
Chemical oxidants	FMC Corporation (n.d.); March 1968.	Potassium permanganate plus Chromic Acid and Nitric Acid	6
		Chloroiodides	4, 7
		Ruthenium tetroxide	3, 4, 8
Ozonation	Arisman et al. 1981; Lacy and Rice Deschlaeger 1976; Prengle and Mauk 1978.	GE UV/ozonation process	2
Chlorine removal	U.S.P. 346, 636	Molten aluminum/distillation	14
Dehydrochlorination	Chu and Vick 1985; Lapiere et al. 1977.	Catalytic:	2, 3
		Nickel on kieselguhr	2, 3
		Pd on charcoal	2, 3
		Lithium aluminum hydride	2, 3
		Butyl lithium	2, 3
		Raney Nickel	2, 3
Reducing agents	Chu and Vick 1985; Sworzen and Ackerman 1982.	Sodium in liquid ammonia	7, 9
		Nickel-catalyzed zinc reduction	7, 9
		Hydrazine	7, 9
		UV light plus hydrogen	2
		Mildly acidic zinc powder, Sweeney and Fischer (1970)	2, 14
Nucleophilic substitution	Brown et al. 1985a; Brunelle and Singleton 1985; March 1968; New York University 1984; Ruzz et al. 1985; Smith and Gurbacham 1981; Sunohio (n.d.); Sweeney and Fischer 1970; United States Patent Office 1984b; Weitzman 1984; Weitzman 1984; Weitzman 1985.	Sodium-based processes;	
		Goodyear, sodium in naphthalene (1980)	10
		Acurex, proprietary solvent	10
		PCBX/Sun Ohio	10
		PPM	10
		Ontario Hydro Power	10
		Potassium poly (ethylene glycolate) based:	
		EPA In-house KPEG	1
		KPEG Terraclean-C1	1
		GE KOH-PEG	11
		New York University KPEG	12
Radiant energy	Bailin and Hertzler 1977; Bailin and Hertzler 1978; Bailin et al. 1978; Craft et al. 1975; Dev et al. 1985; Kalmaz et al. 1981; Meuser and Weimer 1982; Plimmer 1978; Rogers and Kornel 1985; Rogers 1985; Trump et al. 1979; West et al. 1983.	UV/photolysis	3
		Syntex photolytic	3, 4
		Thermal corona glow	5
		Microwave plasma	9, 17
		RF insitu heating	18
		Gamma radiation (Craft et al. 1975)	9
		LARC	1
Electromechanical reduction	Massey and Walsh 1985.	Electromechanical research process	14
Chlorinolysis	Sworzen and Ackerman 1982.	Hoechst process	9
		Goodyear catalytic hydrogenolysis	9
		Exhaustive chlorination	9
Pyrolysis	Boyd 1985; New York State Department of Environmental Conservation 1985a; New York State Department of Environmental Conservation 1985b.	Advanced Electric Reactor	1
		Wright-Malta alkaline catalyst fuel-gas process	12

Table 1. (Continued)

Generic technology	References	Process	Evaluatio
Physical			
Removing and concentrating	*Angiola and Soden 1982; Caron 1985; Gilmer and Freestone 1978; Githens 1984; Hancher et al. 1984; Hawthorne 1982; Lee et al. 1979; Saunders 1985; Schwinn et al. 1984; Versar, Inc. 1984.*		
Heated Air Stripping		*American Toxics Disposal, Inc.*	*14*
Extraction		*Critical Fluid Systems,* CO_2	*14*
		Furfural	*15*
		Acurex solvent wash	*1*
		O.H.M. extraction	*1*
		Soilex process	*1*
Adsorption		*Carbon adsorption, general*	*13*
		Neoprene rubber adsorption	*15*
Vitrification	*Timmerman 1985.*	*Battelle vitrification process*	*1*
Stabilizing	*Ghassemi and Haro 1985; Law Engineering Testing Company 1982; Stroud et al. 1978; Subnamanian and Mahalingam 1977; Tittlebaum et al. 1985.*	*Asphalt with lime pretreatment*	*16*
		Z-Impremix	*15*
		Sulfur-asphalt blends (K-20)	*16*
		Ground freezing	*13*
Bottom recovery	*Carich and Tofflemire 1983; Hand and Ford 1978; Murakami and Takeishi 1978; U.S. Army Corps of Engineers Water Resources Support Center 1983; Zimmie and Tofflemire 1978.*	*Dredging*	*13*
Biological			
Microorganisms	*Bedard et al. 1985; Bumpus et al. 1985; Clark et al. 1979; Dawes and Sutherland 1976; Furakawa 1982; Isbister et al. 1984; Kong and Sayler 1983; McCormick 1985.*	*Bio-Clean*	*1*
		Sybron Bi-Chem 1006 PB	*1*
		Composting	*1*
		Bio-Surf	*4, 13*
	New York State Department of Environmental Conservation 1985a; New York State Department of Environmental Conservation 1985b; Rhee et al. 1985b; Rhee et al. 1985; Unterman et al. 1985.	*Ecolotrol, Inc.*	*4, 13*
		Wormes Biochemical's Phenoback	*11, 13*
		Rhee anaerobic degradation	*14*
Enzymes	*Catelani et al. 1971; Rochkind et al. Unterman et al. 1985*	*No processes found*	

[a]Explanation of process rating:

1. *Identified emerging sediment treatment process.*
2. *Destruction efficiency appears to be too low to meet environmental goals.*
3. *Processing time appears to be extremely long for practical timely cleanup.*
4. *Data available for dioxin, other chlorinated compounds, or other contaminants, but not PCB's.*
5. *Process has been shown to destroy PCB's in gas streams only. It may be feasible for sediments, but has not been shown to be.*
6. *PCB's with 5-7 chlorine atoms per molecule are not destroyed.*
7. *Products of partial degradation may be toxic.*
8. *Reagent is very costly/toxic or both.*
9. *Process costs appear to be excessively high compared with other emerging treatment processes.*
10. *Water destroys the reagent or interferes with its action, thus the process would require excessive drying of sediments and, probably, extraction in pretreatments. The process would therefore have application only as a subordinate final step to several extraction and concentration operations*
11. *This particular process was not evaluated because data were not available for assessment.*
12. *This process is an alternative to another process using the same generic tehnology, but it is in very early stages of development, and data were not available for assessment.*
13. *This technique is basically applicable to preliminary operations prior to treatment or to treatment of wastestreams (e.g., wastewaters) from chemical or physical treatments.*
14. *This process is in the concept stage and data are insufficient to assess it for PCB-contaminated sediments.*
15. *This process has been found to be ineffective.*
16. *This technology provides only for encapsulation of the PCB-contaminated sediments.*
17. *This process supports incineration of PCB's.*
18. *The process does not appear to be feasible for submerged sediments.*

Table 2. *Criteria and Technical Factors Used in Process Assessment*

Criteria/Factor	*Description*
Criteria	
Estimated Residual PCB	*The goal set for process performance was to reduce the PCB concentration in treated sediments to background levels of 1 to 5 ppm. Several of the processes were found to meet this goal.*
Available Capacity	*Although available capacity was found not to exist for any of the processes, several were developed sufficiently to permit projections of the time required to build a facility for application of the treatment.*
Conditions/Limitations	*These include tolerance for water, required processing time, controllability, extent of destruction/decontamination, number of stages of extraction required, and limits on the concentration of PCBs that could be treated. Some processes required one day or less for cleanup; some biological processes required more than 3 weeks.*
Concentration Range Handled	*The PCB concentration of the sediments treated ranged from unknown to 3000 ppm. Some processes had limits inherent in the technology.*
Status of Development	*Processes were found to range from concept stage to completed field test stage. Most were in the pilot stage of testing.*
Test and Evaluation Data Needs	*Data needs varied with the status of the process development. At worst, data were available showing tests of the concept. At best, the process had been field tested, and only permits and checkout were needed.*
Estimated Cost	*The estimated costs of treatments were made in terms of the cost per cubic meter of dry sediment treated, assuming a density of 1.68 Mg/m^3, plus costs of associated operations-dredging, transportation, handling of treated sediments, as required. All costs are stated in 1985 dollars.*
Factor	
Unit Operations	*The process technology was described, including the active agents, the principles and mechanisms of PCB destruction, and complete characterization of all unit operations.*
RCRA Waste Generated	*Some processes have hazardous wastes as residuals from the treatments applied.*
Estimated D/D/R Efficiency	*All the processes achieved a better than 90% destruction/detoxification/removal (D/D/R) efficiency.*

The application of any treatment process can involve the need for one or more of the following unit operations: dredging, transport, storage, landfill disposal, land treatment disposal, incineration, and/or alternative treatment. Estimates were developed for all of these so that, in any given process evaluation, the proper elements could be added to obtain an estimate of the cost of application. The estimates were made in terms of the cost per cubic meter of sediment treated. The sediment was assumed to have a density of 1.68 Mg/m^3.

Dredging costs for those treatments requiring removal of the sediment before treatment are estimated at $20/$m^3$ based on the recent experience of the U.S. Army Corps of Engineers in contracting for dredging in the New York State area.

Transport costs are given as a range. The Corps' experience is $13/$m^3$ for short hauling distances. A cost of $126/$m^3$ was used for long hauling distances, which represents an assumed 483-km average transport distance to RCRA landfills capable of accepting PCB-contaminated wastes.

Storage cost will sometimes be incurred to hold the dredged sediments pending treatment; e.g., where dredging rates exceed the rates at which the treatment can be applied. These have been set arbitrarily at $10/$m^3$.

Land treatment involves the controlled application of wastes to the surface of the soil. At land-treatment facilities, wastes are either spread on or injected into the soil, followed by tilling into the soil with farm equipment. The physical and chemical properties of the soil, in unison with the biological component of the soil and sunlight work together to immobilize, degrade, and transform portions of the wastes. The application and tilling process can be repeated many times on the same plot, making land treatment a dynamic system designed to reduce and ultimately eliminate a portion of the waste, as opposed to permanent storage such as landfills.

The American Petroleum Institute in 1983 reported that there were 213 land-treatment facilities in operation handling waste from 16 different industry sectors. The most extensive use of land treatment is for petroleum refinery wastes, with 105 land-treatment facilities, many of which are located on the same site as the refinery. More recently, EPA verified the existence of 114 land-treatment facilities and obtained information on operating parameters at some of these sites.

Wastes are typically mixed to a depth of 0.5 to 1.0 feet, where biochemical reactions take place. Application frequencies can range from daily to yearly, with tilling occurring as frequently as daily.

The average cost of controlled, managed land treatment cited by the American Petroleum Institute, $60/ton, equates to $111/m^3$ of sediments. For short-term land treatment of readily-degradable solvents remaining in treated sediments free of PCBs after they are washed or dried, the cost is estimated at $33/m^3$.

Redeposition costs of decontaminated sediments were also estimated at $33/m^3$. Slightly lower costs might be expected in special cases.

Because the regulations permit the use of incineration or chemical waste landfill and the application costs of these two methods are available from firms engaging in their practice, these costs were used as lower and upper limits with which to compare the costs of applying new alternative technology.

Landfill disposal costs, incurred when the sediments must be placed in authorized chemical waste landfills, are estimated as ranging from $260/m^3$ for the Michigan area (EPA Regional Office) to $490/m^3$, based on the highest prices charged for hazardous wastes by commercial facilities. This range includes an intermediate value reported by the Corps of Engineers: $420/m^3$.

Costs for incineration techniques capable of achieving 99.9999 percent destruction and removal efficiencies for PCBs are difficult to predict. Even more difficult is prediction of the price commercial facilities will charge to accept the responsibility of handling such a sensitive waste. Surveys made to determine the likely charges to incinerate dioxin-containing wastes resulted in a reported price on the order of $1,000/Mg. This translates to $1,680/m^3$, the value adopted for this evaluation, and the cost of disposal of residue from incineration is included. The total cost of use of incineration including dredging at $20/m^3$ and transport at $13 to $126/m^3$ is $1713 to $1826/m^3$.

When available, alternative treatment costs were obtained from the proponent of the process. Otherwise, they were estimated based on the types of unit processes involved and the environmental controls required, or they were determined not to be estimable considering the status of development of the process.

While all costs are in 1985 dollars, the treatment costs are not all necessarily based upon the same labor rates, corporate fixed charges, or profit. These costs vary from one firm to another. The cited estimates are costs of purchasing the treatments. Further cost analyses will be needed to provide a basis for comparison of processes on the basis of individual cost elements.

Table 3 shows the unit cost estimates used to develop cost ranges for the emerging treatments.

Estimated costs were rated by comparing the range of the cost estimates obtained with the cost of placing them into a chemical waste landfill. Treatment processes showing the lowest estimated cost range were rated "6"; those showing a probable cost lower than landfill were rated "4"; those showing an estimated cost equal to landfill were rated "2"; and those showing an estimated cost range greater than landfill were rated "1".

Overall ranking was accomplished through the use of weighting factors assigned to each rated factor. The weighted average rank was then obtained by summing the products of the weighting factors and the ratings and dividing by the sum of the weighting factors. The weighting factors were:

Factor	Weight
Residual PCB concentration	5
Capacity	2
Conditions/limitations	3
Concentration range handled	2
Status of development	2
Test and evaluation data needs	1
Estimated costs	4

The weightings tend to give greatest emphasis to the ability of the treatment to reduce the PCBs and to the probable cost of the treatment. Much less emphasis is placed on the status of development. Thus, an almost fully developed process with an extremely high cost would be ranked lower by application of the weighting process than a less developed process with a much lower potential cost. Test and evaluation data needs have not been heavily weighted because nearly all the alternative treatment processes that show low potential cost require more data to be proven.

Under this procedure, the perfect process for treating PCB-decontaminated sediments would show the following levels for each ranking factor and would receive, using the ratings given, a weighted rating of 6.0:

Table 3. *Unit Costs Estimates for Steps Involved in Treatment and Disposal of PCB-Contaminated Sediments*

Operation	*Cost, $/m³*
Dredging	*20*
Transport	*13 to 126*
Storage	*10*
Landfill and Disposal	*260 to 490*
Landfarming	*33*
Restricted Land Disposal	*111*
Incineration	*1680*

Factor level	Rating, R	Wt	R × Wt
1. Residual PCB, treated sediment less than 1 ppm	6	5	30
2. Capacity adequate for site cleanup available in 12-16 mo.	6	2	12
3. Tolerates to 40 percent water and treats in 1 day (24 hr)	6	3	18
4. Handles concentrations greater than 3,000 ppm	6	2	12
5. Commercial system designed and ready for construction	6	2	12
6. No test and evaluation data needs except permits and checkout	6	1	6
7. Lowest estimate cost range among alternative emerging technologies	6	4	24
Total R × Wt ΣR × Wt			114
Weighted rating(ΣR × Wt)/ΣWt			6

Process Assessment

The processes were assessed by characterization and ranking. Characterization provided for objective comparison of the processes. Ranking provided a subjective comparison of the processes based on the seven criteria.

Characterization

Table 4 summarizes five characteristics of the processes: unit operations, available capacity, conditions/limitations, concentration handled, and any generated RCRA wastes. The unit operations employed are given, and each is identified by a number. Generally, a greater number of unit operations will mean a greater effect on treatment costs.

None of the processes has currently available capacity approaching that required for major cleanups. Therefore, the time required to build capacity is listed. Construction time ranges from 12 to 24 months.

Certain conditions that typify the process or limit its versatility are given in column 4 of Table 4. Table 4 also identifies any RCRA waste streams generated by the process.

The data from studies of the processes were examined for ranges of PCB concentrations handled to date. Generally, the values are not limitations on the process, but only on the data acquired. The value ≤300 ppm for the Bio-Clean process may, however, be a limitation requiring process adjustment to control.

Table 5 lists five additional characteristics of the processes and the rating developed in the ranking process. The characteristics shown here relate to the needs for further process development and evaluation. The process status is given in terms of stages of development completed. The processes range in stages completed from concept to pilot plant.

Both PCB destruction and residual PCB concentration in treated sediments are given to the extent available. Certain processes may require extension of the unit operations employed (e.g., more stages of extraction) to attain the required performance levels.

Test and evaluation data needs are indicated for each process. Needs vary from one (Advanced Electric Reactor process) to complete site-specific evaluation.

The estimated costs of applying the ·ocess are listed in \$/m^3. Although cost estimates lack the necessary accuracy at this stage of development of the alternative processes to serve as the sole criterion of potential, they nevertheless indicate that seven of the processes may cost no more than landfill and five could cost less. (Cost estimates could not be made for the Sybron process and composting.)

Ranking of Treatment Processes

In contrast to process characterization which involves all factors listed in Tables 4 and 5, ranking is subjective and is based on the seven criteria previously described. An attempt was made to define and determine a single number that could represent the overall position of each process relative to an arbitrarily defined perfect process.

Based on the weighted ratings, the processes rank as follows from highest to lowest: KPEG, LARC, Acurex, Bio-Clean, Modar-Supercritical Water, Advanced Electric Reactor, Vitrification, OHM Extraction, Soilex, Composting, and Sybron Bi-Chem 1006 PB/Hudson River Isolates.

Conclusions

Emerging treatment processes for decontamination of sediments containing PCBs that show potential as alternatives to incineration and chemical waste landfill have been identified. Eleven alternative treatments were compared and ranked using technical performance, status of development, test and evaluation data needs, and cost as factors. The first eight processes show potential for reduction of PCB concentrations to the desired background levels (1-5 ppm) or less, with minimum environmental impacts and low to moderate cost. The sediments must be dredged for application of these treatments.

Of the 11 processes assessed, all but the Advanced Electric Reactor (AER) are in various stages of development from laboratory-scale through field tests. The AER is a permitted treatment under TSCA in EPA Region VI, based on completed trial burns. There is no immediately available capacity for any of the treatment processes. Further data are needed in most cases to define the final system designs for the processes.

At this stage, estimated costs of application of these 11 processes are less than or within the range of costs of chemical waste landfill, except for the AER estimated cost, which exceeds that of landfill, but is less than incineration. These costs are planning estimates only. In most cases, further research is needed to provide data suitable for more definite cost estimates.

The emerging treatment processes are based on six types of generic technologies: low-temperature oxidation, chlorine removal, pyrolysis, removal and concentration, vitrification (melting), and microorganisms. Types of generic technologies not yielding competitive emerging processes are: chlorinolysis, stabilization, and enzymes. A search of these technologies yielded no suitable candidate processes at this time.

On the basis of the comparisons made, the treatment processes were ranked in the following order from highest to lowest. The estimated cost range (1985 dollars) per cubic meter of sediment treated is also shown for each process. Costs of chemical waste landfill and incineration are given for comparison.

KPEG	\$211-378
LARC	\$223-336
Acurex Solvent Wash	\$196-569
Bio-Clean	\$191-370
Modar Supercritical Water	\$250-733
Advanced Electric Reactor	\$830-942
Vitrification	\$255-548
OHM Methanol Extraction	\$400-514
Soilex Solvent Extraction	\$856-913
Composting	Unable to estimate cost
Sybron Bi-Chem 1006	Unable to estimate cost
Chemical Waste Landfill	\$260-490
Incineration	\$1713-1826

Table 4. *Treatment Process Assessment*

Process	Unit operations	Available capacity (or time to provide)	Conditions and limits	Concentration handled	RCRA waste generated
Chemical					
Supercritical water oxidation	1,4,10	—	20-40% solids; 374°C, 23.3 MPa organic content >5% or supplemental fuel	>3000 ppm	None
KPEG, Terraclean-CL	1,3,4,7	(24 mo)	150 °C, 0.5-2 h	500 ppm or greater	w.w.tr. act. carbon
KPEG, NYU	1,2,3,4,5,6,7,9	—	—	—	—
KPEG, EPA in-house	Fundamental studies				
LARC	1,2,5,15	(24 mo)	tolerates 25% water.	480 ppm	None
Advanced electric reactor (I.M. Huber)	7,8,12,13,14	(16 mo)	2204°C, 2,400 kWh/m^3 needs predryer	>3000 ppm	None
Physical					
O. H. Materials methanol extraction	2,7,8,14,15	—	predry to <1% moisture	>400 ppm	PCB-loaded carbon from solvent cleanup
"Soilex" kerosene/water	1,2,5,15	—	25% of kerosene solvent retained in soil; 3 d per batch	to 350 ppm tested	Concentrated PCB from still to incineration
Acurex solvent wash	2,4,5,6,10,11	—	3-12 washes, tolerates <40% water.	up to 1,983 ppm	Concentrated PCB's to KPEG
Vitrification	8,12,14	—	Electrical power usage increases with soil moisture; submerged sediments dredged and treated	500 ppm	None
Biological					
Composting	15,16	(16 mo)	Seasonal effects, reaction time must be >4 weeks	1,590 ppm	Treated material is still a RCRA waste
Bio-Clean	1,2,17	27 m^3/d available, 12 mo for full-size	Proved for PCP, laboratory confirmed for PCB's	≤300 ppm	None
Sybron Bi-Chem 1006	15,17	—	Unknown	Unknown	Unknown

NOTE—Unit operations key:

1. Liquid/solids separation
2. Extraction/solubilization (liquid-solids)
3. Liquid/liquid extraction
4. Chemical reactor
5. Stripping still
6. Solvent recovery still
7. Adsorption
8. Dryer (solids)
9. Dryer (liquids)
10. Filtration
11. Steam cleaning
12. Thermal reactor
13. Grinding
14. Air pollution controls
15. Landfarm
16. Innoculation/digestion
17. UV light reactor

Table 5. *Treatment Process Assessment*

Process	Status[a]	Estimated D/D/R efficiency, %[b]	Estimated residual PCB, ppm	Test and evaluation data needs	Estimated costs, $/m^3$	Rating[c]
Chemical/physical						
Supercritical water oxidation, Modar	Field test with PCB liquids	>99.9995	<0.1 ppb	1,2,3,4,5,6,7	250-733	4.58
KPEG Terraclean-CL	Pilot tests	>98	<1 ppm	1,6	208-375	5.42
LARC	Lab tests	>90	38-50	2,3,4,5,6,7	223-336	5.26
Advanced electric reactor	Pilot tests	>99.9999	<1 ppb	None[d]	830-943	4.58
Physical						
O. H. Materials, methanol extraction	Field tests under way	97	<25 ppm	2,3,6,7	401-514	4.16
Soilex	Pilot tests	95 (3 stages)	6-9 ppm	5,6,7	856-913	3.26
Acurex solvent wash	Pilot-scale (field tests planned)	[e]	<2 ppm	Identity of mixed solvent, 6,7	196-569	5.21
In-situ vitrification Battelle Pacific NW for EPRI	Pilot test of soil	99.9	None in vitrified block, 0.7 ppm in adjacent soil	6	255-548	4.53
Biological						
Composting, aerobic	Lab-scale	62	504-908	4,5,6	—	2.47
anaerobic	Lab-scale	18-47	825-1268	4,5,6	—	2.47
Bio-Clean, aerobic	Bench-scale	99.99	25 ppb	3,5,6,7	191-370	4.84
Sybron Bi-Chem 1006	Lab-scale and concept	50	—	3,4,5,6,7	—	1.48

NOTE—Data needs key:

1. D/D/R data
2. Residual PCB data
3. Unit operations data
4. Bench-scale data
5. Pilot-scale data
6. Field test data
7. Cost data
8. RCRA waste

[a]Status is defined in terms of the types of studies completed.

[b]D/D/R = destruction/detoxification/removal.

[c]The rating was obtained as shown by the example, under Characterization.

[d]AER is fully permitted under TSCA in EPA Region IV for destruction of PCB.

[e]Treatment is continued until a residual of <2 ppm PCB's is obtained.

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***Donald L. Wilson** is the EPA Project Officer (see below).*
The complete report, entitled "PCB Sediment Decontamination—Technical/Economic Assessment of Selected Alternative Treatments," (Order No. PB 87-133 112/AS; Cost: $18.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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