



Project Summary

Waste Minimization in the Printed Circuit Board Industry— Case Studies

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The full report presents information on waste minimization practices currently employed in the printed circuit board (PCB) and semiconductor manufacturing industries. Case studies conducted at six facilities evaluated the technical, environmental and cost impacts associated with the implementation of technologies for reducing the volume and toxicity of PCB metals-containing sludges and solvent wastes. The analyses of these data are the basis for demonstrating waste minimization technologies to reduce hazardous waste.

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 purpose of this project was to evaluate the effectiveness of various waste minimization practices or technologies in the printed circuit board and semiconductor manufacturing industries. The most significant waste streams in these industries are waste halogenated solvents from photoresist stripping and developing operations (RCRA Waste Code F001-F003), and metal-bearing sludges (RCRA Waste Code F006) from the treatment of metal plating and etching rinsewaters. This Project Summary presents the findings of case studies conducted at five printed circuit board manufacturing facilities and one commercial treatment/recovery facility.

Each facility investigated employs some practice that requires offsite disposal. Two of the case studies focus on the recovery of spent halogenated solvents, and the remaining four discuss the recovery or reduction of metal plating and etching process wastes. Table 1 summarizes characteristics of facilities investigated that range from small job shops to large integrated facilities.

Metal Plating Bath Waste Minimization Case Studies

Metal plating wastes generated from plating bath dumps, rinses, etching machines and scrubbing operations generate copper-, nickel-, tin-, and lead-contaminated wastes. Four of the six case studies investigated under this research project focus on the minimization of sludges generated primarily by copper plating and etchant baths and copper and tin/lead rinsewaters.

The common objectives of each of the technologies evaluated are: (1) minimization of metals sludges generated; (2) compliance with effluent guidelines or local discharge limitations; and (3) reduction in operating costs over other conventional alternatives. The following discussion briefly summarizes each case study, the nature of the minimization technology, the measurements data collected and the results obtained.

Facility A

Description

Facility A is an offsite Treatment, Storage, and Disposal (TSDF) facility which processes concentrated dumps

Table 1. Summary of Facilities Tested Under Waste Minimization Case Study Program

Facility Name	Description	Wastes Treated/Reduced	Technology	Residuals
Facility A	Treatment storage disposal facility handling electroplating baths, waste etchants, spills, etc. Capacity: 1,000 gph (24,000 gpd).	—Nickel plating baths —Copper plating baths —Cyanide	—Sodium hydroxide precipitation —Sodium borohydride reduction —Alkaline chlorination	Sludge product
Facility B	Contract PC board manufacturing shop Employees: 77 Production: 500,000 sf/yr Sales: \$7 Million/yr	—Cupric chloride etchant —Electroless plating rinses —Electroplating rinses	—Sodium borohydride reduction —Memtek ultrafiltration system	Sludge product
Facility C	Computer manufacturer. Employees: 10,000	—Methyl chloroform resist developer —Freon resist developer	—Solvent distillation/fractionation recovery of resist developers.	Still bottoms
Facility D	Electronic equipment mfr. PC board manufacturing using the subtractive technique in the MacDermid process. Employees: 260	—1,1,1-trichloroethane resist developer —1,1,1-trichloroethane still bottoms	—2-stage solvent distillation —(1) DuPont RISTON SRS-120 solvent recovery still —(2) Recyclene Products, Inc. RX-25 still	Still bottoms
Facility E	Computer manufacturer. PC board manufacturing using additive techniques. Employees: 600 Production: 600,000 sf/yr	—Acid copper plating bath	—Activated carbon regeneration of spent plating baths.	Spent activated carbon
Facility F	PC Board manufacturer 2-sided single layer circuit boards. Production: 480,000 sf/yr	—Acid copper plating rinsewaters —Tin/lead plating rinsewaters	—Agmet Equipment Corp. —Electrolytic recovery units.	Metal foil

from the metal plating and printed circuit board industries, including alkaline etchants, acid plating baths, nitric acid rack strip baths, and electroless plating cyanide baths. The average total metals concentration in the incoming waste was reportedly 12 g/L (12,000 ppm). These waste streams are classified into the following four categories: (1) acidic metals solutions; (2) alkaline metals etchant solutions; (3) cyanides; and (4) chelated metals solutions. The case study for this facility focuses on the use of a sludge minimizing treatment technology for the metals and cyanides wastes.

Initially, the facility was designed to operate using lime and ferrous sulfate precipitation of metals as the primary means of waste treatment. When the high cost of land disposal of the lime sludges was considered, alternate means of treating and disposing of the waste were evaluated.

The unit processes selected to detoxify the wastes and recover metals at Plant A currently include sodium hypochlorite

oxidation of cyanides (alkaline chlorination), sodium hydroxide precipitation, pH adjustment, sodium borohydride reduction (with sodium metabisulfite stabilization), sedimentation, plate and frame filter press (for sludge dewatering), rapid sand filtration, and ion exchange columns for effluent polishing.

Results

The primary purpose of the Facility A case study was to evaluate sodium borohydride as a viable waste treatment alternative for reducing RCRA Hazardous Waste Code F006 spent electroplating baths. The evaluation criteria were the ability of sodium borohydride (SBH) to effectively meet local compliance standards and produce a high density, low-volume sludge. The test program evaluation relies mainly on the trace metals results to evaluate system performance.

The SBH reactor was sampled for trace metals on the influent, effluent, and sludge streams. Both filtered and unfiltered samples were collected and analyzed for eight selected metals. The

unfiltered sample showed little or no reduction as expected. However, the filtered sample showed individual metals reduction efficiencies which ranged from 16.1 to 99.8 percent. The observed range in efficiency data was attributed to variations in concentration and chemical potential (quantity of free energy required for an ionic species to obtain equilibrium) of each of the metallic ions contained in the solution. Overall, SBH was able to reduce 6.91 kg of the initial influent metals loading of 7.25 kg. These results represent a greater than 95 percent reduction in total metals for a complex waste stream. The remainder of the metals influent loading (0.337 kg) consisted of over 70 percent calcium.

An additional objective of this program was to evaluate the ability of Facility A to consistently meet local pretreatment requirements. The resultant data for two separate batch runs showed discharge in excess of effluent limits, apparently due to incomplete polishing caused by cation exchange column breakthrough. Since the test program was completed

Facility A has instituted the use of a quality control holding tank and further waste processing optimization to remedy these problems. Follow-up discussions with the local sewer authority revealed that Facility A's effluent quality has improved considerably and is now consistently meeting compliance guidelines.

In addition to assessing wastewater effluent characteristics, the testing program was designed to evaluate uncontrolled process air emissions. The results were obtained by Draeger tube analysis of grab and integrated samples of exhaust gases taken from the process reactor exhaust ducts. The emission results showed a frequent presence of hydrochloric acid and hydrogen gas accompanied by occasional presence of ammonia and sulfur dioxide. One of the hydrogen emissions grab sample results (6.0 percent) is significant since this value is greater than the lower flammable limit for hydrogen (4.0 percent). Grab sample concentrations for ammonia and sulfur dioxide also exceeded adopted short-term exposure limits (STEL) for these substances.

Analysis of the nickel/cyanide and SBH sludges shows total metals contents (dry weight) of approximately 35 and 6 percent, respectively. Neither sludge result supported Facility A's claim of 60 to 70 percent metals content (dry basis). While the SBH sludge result was significantly below performance expectations (70 percent metals), the exact cause of these results was not discernable. Possible explanations include: (1) a possible process upset; (2) sampling error; and (3) analytical error. It seems most probable that a process upset was responsible for these results, since blinding of the sludge press occurred on the SBH press. Based on other SBH reduction case study results conducted under this program, it is reasonable to assume that these results are not representative, since typical sludge metals contents should be greater than 70 percent.

EP Toxicity analyses were also conducted for both the nickel/cyanide and SBH reactor sludges. The results of the tests clearly show that for Facility A influent metals concentrations, the SBH sludge produced is fairly stable in that its leachate characteristics are below EP Toxicity limits for all metals. However, note that the waste is still classified as F006 hazardous waste.

Another objective of the Facility A case study was to evaluate the ability of SBH

to economically reduce F006 waste streams. At the time of testing, Facility A reduction chemistry was very inefficient at \$19.80/lb of copper reduced. However, through process optimization, chemical costs have reportedly decreased over 63 percent, bringing process economics within acceptable limits. The case study follow-up for Facility A has indicated that the cost of copper reduction has been lowered to \$7.27/lb of copper.

Facility B Description

Facility B is a captive printed circuit board manufacturing facility employing 77 people in Santa Ana, California. Gross sales are approximately \$7 million annually on production of 500,000 ft² of board. Production at Facility B uses a special hybrid process, employing elements of both additive and semi-additive printed circuit production techniques. Process wastes of interest to this study include rinsewaters from the electroplating and etchant baths. The principal components of the acid copper electroplating baths are copper sulfate and sulfuric acid. Facility B uses a slower acting etchant (sodium chloride, sodium chlorate, and muriatic acid) which etches copper from the board, and yields cupric chloride in the waste stream.

Facility B uses a rather unique end-of-pipe treatment system employing SBH treatment and ultrafiltration (Memtek) technology for solids separation. In this process, incoming plating and etching wastes are adjusted to pH 7-11 by adding sodium hydroxide or sulfuric acid. Sodium borohydride is added to obtain an oxidation reduction potential (ORP) of approximately -250 mv or less. The reacted waste then feeds from the concentration tank to a Memtek ultrafiltration unit from which the permeate is discharged to municipal treatment, and the concentrate is returned to the concentration tank. A small plate and frame sludge filter press dewateres the sludge which is drawn from the bottom of the concentration tank.

Points of interest in evaluating the Facility B waste treatment system for this case study were: (1) compliance of the ultrafiltration permeate (wastewater discharge) with local and Federal discharge standards; (2) the volume and EP toxicity of the sludge filter cake; and (3) economic evaluation against comparable technology (lime and ferrous sulfate treatment).

Results

The objective of the sampling program was to evaluate the effectiveness of the SBH technology in use by Facility B. The effectiveness was measured in terms of metal reduction efficiency and minimization of hazardous waste streams. Data derived from the metals concentrations in the influent and effluent streams were used to determine the effectiveness of the SBH reduction system in both meeting effluent guidelines and minimizing releases to the environment.

Analysis of the influent and effluent streams metals characteristics showed that copper was reduced most efficiently (99.82 percent), while nickel reduction was the least efficient (45.5 percent). Differences in removal efficiencies were attributed to variations in concentration (higher removals for higher concentrations), but the chemical potential may also have been a factor. Approximately 144.7 lb of combined metals were reduced to elemental form by the SBH reaction system, representing a combined reaction efficiency of 99.8 percent. Despite deviations from design operating conditions, the SBH/ultrafiltration system performed very well. EP Toxicity leachate test results for Facility B filter press sludge clearly show that the SBH sludge produced is fairly stable. Leachate characteristics are below EP Toxicity limits for all metals. However, note that the waste is still classified as F006 hazardous waste.

In addition, an economic comparison of the use of SBH versus lime-ferrous sulfate chemistries was conducted. The results demonstrate that in this application, SBH would be superior to lime-ferrous sulfate for the following reasons: (1) sludge disposal costs and volumes would be reduced by 93.5 percent; (2) overall operating expenses would be 48 percent lower; and (3) sludge generated by the SBH reduction process was 78 percent copper and suitable for reclamation (due to the high copper content).

The use of the SBH and ultrafiltration treatment at Facility B is favored by the use of the chloride etch process in lieu of the more commonly preferred ammonium peroxide etch. The ammonium-based etchants create borohydride sludge stability problems which require tighter treatment process control and use of stabilizers such as sodium metabisulfite. Additional factors that favor the economics of SBH treatment at Facility B include: (1) the use of cupric chloride etchant; (2) high copper concentrations

and low organic loadings seen at this facility; and (3) low effluent limitations required by the sanitation district.

Based on the above results, it appears that SBH reduction is an effective technology which can be utilized to reduce complex metal electroplating sludges and render them reclaimable, and possibly less hazardous. Note that the economics of SBH technology is highly dependent on site-specific factors and warrants a detailed study prior to implementation.

Facility E

Description

Facility E began operations in January 1982 as a manufacturer of customized, fine-line multilayer printed circuit boards. Facility E initiated an ambitious waste minimization program in mid-1984. Since that time, production has roughly doubled, but liquid discharge to the wastewater treatment plant has remained constant and wastewater sludge generation has dropped roughly 30 percent. Waste minimization efforts continue to center around in-process modifications to use nonhazardous or reclaimable solutions, to reduce water consumption and bath dump frequency, and to optimize wastewater treatment operations.

At Facility E, boards are pattern plated with eight acid copper and one aqueous tin/lead plating baths in a 48-tank plating line. The line begins with a nitric acid (HNO_3) rack strip tank. After the racks are stripped, boards are loaded and then undergo rinsing, cleaning with phosphate solutions (H_3PO_4 , Electro-clean PC2000), and more rinsing before being plated. Acid copper baths contain CuSO_4 , organic brighteners, and chlorides with copper concentrations of 24 oz/gal. The general processing procedure is to activate the board surface (HCl), plate, clean/rinse and replate.

In plating operations, addition agent and photoresist breakdown products will incrementally accumulate and contaminate an electrolytic (charge carrying) plating bath. In the absence of a bath regeneration system, the manufacturer would typically be forced to either discharge the spent plating bath to the wastewater treatment plant or send it offsite for disposal. In either case, large quantities of metals containing sludge (RCRA Waste Code F006) would be generated and subsequently land disposed. At Facility E, these spent plating

baths are regenerated through activated carbon filtration (used to remove built-up organic bath contaminants) and then returned to the process. Copper and solder plating baths are treated with activated carbon once every three months and every month, respectively. The frequency of cleaning is determined by organic contaminant build-up. Electroplating baths never have to be dumped with this arrangement under normal processing conditions.

Activated carbon treatment is performed in a batch mode for acid copper, solder and nickel microplating baths in three separate systems. The bath reclamation system consists of a holding tank, mixing tank, and MEFIAG paper-assisted filter. For acid copper treatment, 2,400 gallons of contaminated solution is pumped into a 3,000-gallon mixing tank. Hydrogen peroxide is added and the temperature of the bath is maintained at 120 to 130°F for 1 hour. Powdered activated carbon (80 lb) is added and the contents are mixed for 3 to 4 hours to oxidize volatile organic species. The solution is recirculated through a paper-lined MEFIAG filter several times to remove the activated carbon. The filter solids and paper are removed as needed when a predetermined pressure drop across the filter is reached. When the bulk of the activated carbon has been removed (generally after three passes of the solution through the filter), the filter is precoated with 5 gallons of diatomaceous earth. The solution is again recirculated through the filter until a particulate test indicates sufficient solids removal (no residue detected on visual examination of laboratory filter paper). Total spent solids from plating bath purification is 1-½ drums every 3 months which is landfilled.

Results

The purpose of this case study was to evaluate the extension of electroplating bath lifetimes (and subsequent waste reduction) by activated carbon removal of organic brightener breakdown products. The acid copper baths were selected for study since recovery of this solution results in the most significant amount of waste minimization.

Sampling and analysis were conducted on three process streams associated with activated carbon bath reclamation. Based on resultant analytical data the following conclusions were drawn:

- Forty-seven percent of the organic by-products and brighteners were

removed from the contaminated solution:

- Low molecular weight organics such as carboxylic acid derivatives are not preferentially adsorbed;
- Reduced sulfur (a brightening and leveling agent) is oxidized and volatilized during treatment; and
- Inorganic contaminants such as tin and lead are also removed (37.5 percent and 24.5 percent, respectively) as a beneficial by-product of the treatment process.

In recovering spent electrolytic plating baths, Facility E was able to save over \$50,000 in hazardous waste disposal and raw material purchase costs. These savings represent a payback period of only 3 months for purchasing the activated carbon recovery system. This relatively short payback period, combined with the volume of plating solution regenerated, make activated carbon treatment a cost-effective and environmentally safe technology for reducing the quantity of hazardous waste that would otherwise be land disposed.

Facility F

Description

Facility F is an independent manufacturer of printed circuit boards. The normal production volume of the facility is 40,000 ft²/month. The major waste streams of interest to this case study are rinsewaters that follow electroplating and etching processes. Prior to implementation of the electrolytic recovery technology being studied, these rinse waters contained copper and lead at concentrations of up to 3,000 mg/L. Because of this, the concentration of these metals in the final effluent exceeded pretreatment standards (4.1 mg/L for copper and 2.2 mg/L for lead) for discharge to the city sewer system. To decrease the concentration of metal in the effluent, the facility converted several rinse tanks into static dragout tanks in order to recover metals from rinse baths following copper electroplating, tin/lead electroplating, electroless copper plating, and a copper microetch process. The quantity of metal recovered from the electroless copper rinse and the copper microetch was small. Thus, the reactors were removed from these bath and installed at the copper and tin/lead

rinse baths where there was more potential for metal recovery.

The electrolytic reactors used at this facility are Agmet Equipment Corp., Model 5200* reactors. They consist of a wastewater sump, a pump, and the anode and cathode, contained within a rectangular box with dimensions of approximately 22 in. x 10 in. x 22 in. The anode was cylindrical and was encircled by a stainless steel cathode with a diameter of 8 in. and a height of 6 in. The anode material used for copper plating solutions is titanium. For tin/lead plating solutions, however, a columbium anode was required because the fluoroboric acid in the tin/lead plating solution was extremely corrosive to titanium. The columbium anode increases the cost of these electrolytic units to \$4,500, as opposed to \$3,500 for the titanium anode units.

Results

At the time of testing, four electrolytic reactors were being used for recovery of copper, and three were being used for recovery of tin/lead. To evaluate the performance of these units, samples of the plating bath, dragout, and rinse bath were analyzed. Conclusions that were drawn based on the resultant data include:

- Recovery of copper from the acid copper solution is very effective—rates of recovery were 4 to 5 grams/hour/unit, representing a current efficiency of nearly 90 percent.
- Recovery of tin and lead was not effective at the time of testing—concentrations of these two metals in the dragout were not significantly less than in the plating bath. However, evaluation of the data was difficult because the analytical results for some of these samples were inconclusive due to matrix interference.
- Use of in-line electrolytic recovery was not able to reduce metal concentrations sufficiently as to enable this facility to meet pretreatment standards.
- Electrolytic recovery would significantly reduce the amount of sludge generated if a lime precipitation system were utilized to remove metals

from the final plant effluent. For this facility, a reduction of 32 tons/year would be realized.

- At a sludge disposal cost of \$200/ton, the annual cost of electrolytic recovery would exceed the savings. However, if sludge disposal costs increased to \$300/ton, the savings (at least for copper recovery) would exceed the processing costs.

Electrolytic recovery methods remove metals from an aqueous solution in a metallic form which allows for the use of the recovered material as scrap metal. Conversely, hydroxide precipitation removes the metal from solution and generates a sludge with a low metal concentration. In most cases, the only method of handling this sludge is landfilling at a high cost. Therefore, electrolytic recovery is useful in minimizing the quantities of metal-bearing sludge that must be landfilled. The cost effectiveness of this type of technology will increase as sludge disposal costs increase in the future.

Resist Developing Solvent Recovery Case Studies

Two case studies evaluated under this program focused upon the minimization of developer solvent wastes and sludges which might require either land disposal or incineration. In general, the recovery of resist stripping and developer solvents is not unique within the PC board manufacturing industry. However, the recovery systems evaluated at the two facilities discussed below represent state-of-the-art technology applications. In the case of Facility C, the technology involves the separation of a two-solvent system with subsequent recovery and reuse of each solvent. In the case of Facility D, the technology evaluated further recovers the solvent bottoms product of the initial recovery unit.

Facility C

Description

Facility C manufactures computing equipment including logic, memory and semiconductor devices, multilayer ceramics, circuit packaging, intermediate processors and printers. One of the major hazardous waste streams that is generated is spent halogenated organic solvents (RCRA Code F002). Methylene chloride is used in resist stripping of

electronic panels. Methyl chloroform (1,1,1-trichloroethane) used in resist developing of electric panels and substrate chips. Freon used in surface cleaning and developing of substrate chips. Perchloroethylene used in surface cleaning of electronic panels.

The spent solvents from photoresist stripping and developing are contaminated with photoresist solids at up to 1 percent, and the solvents used for surface cleaning are contaminated by dust, dirt or grease. Waste solvents are recovered at Plant C by distillation or evaporation and returned to the process in which they were used. Several types of equipment are used including box distillation units to recovery methylene chloride and perchloroethylene, flash evaporators to recover methyl chloroform, and a distillation column to recover Freon.

There are two identical flash evaporators at the facility, each with a capacity to recover 600 gallons of methyl chloroform (MCF) per hour. The flash chamber operates at a vacuum of 20 in. Hg, allowing the MCF to vaporize at 100 to 110°F. The units are operated one to two shifts/day depending on the quantity of waste solvent being generated.

A packed distillation column is used to recover pure Freon from a waste solvent stream containing approximately 90 percent Freon and 10 percent methyl chloroform. Waste is continuously fed to a reboiler where it is vaporized and rises up the packed column. Vaporized Freon passes through the column, is condensed and recovered at a rate of 33 gal/hour. MCF condenses on the packing and falls back in the reboiler. The distillation bottoms are removed when the concentration of methyl chloroform reaches 80 percent (approximately 1 to 2 weeks).

There are also two identical box stills at the facility, each with a capacity to recover 475 gph of methylene chloride. These are very simple units consisting of an 800-gal still pot with hot water heating coils. The contaminated methylene chloride is heated to between 103°F and 108°F, and clean solvent is condensed overhead.

Results

Sampling and analysis were conducted on process streams associated with two of the solvent recovery processes. One of these processes was the flash evaporator used for recovery of methyl chloroform (1,1,1-trichloroethane), and the other was the distillation column

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

used to recover Freon TF from a Freon/methyl chloroform mixture. The conclusions drawn from the sampling and testing program were:

- At least 95 percent of the solids are removed from the solvent waste influent;
- The recovered product is at least as clean as the virgin material; and
- The still bottoms from recovery of contaminated solvent still contain a high fraction (90 percent) of solvent.

The recovery of spent solvents at the facility is motivated primarily by economic benefit. In recovering spent solvent, the company saves over \$10 million annually, compared to offsite recovery. The savings per pound of methyl chloroform, methylene chloride, and Freon recovered is \$0.18, \$0.18, and \$0.61, respectively.

The high cost savings are primarily due to the fact that the solvents recovered are reused onsite, thus reducing the quantity (by greater than 95 percent) of new or virgin solvent that must be purchased. Offsite recovery could be conducted, but at much higher cost. Since the rate of generation of spent solvent is so high, the initial expense of purchasing recovery equipment is quickly returned.

To landfill or dispose of such a large quantity of spent solvent by any other method would be economically unacceptable. Incentives other than economic reasons for onsite recovery include:

- Reduction in the risk of a spill of solvent in transporting the waste to a TSDF; and
- Reduced liability related to an accident at the TSDF resulting in the release of spent solvent.

Facility C is trying to further reduce the quantity of waste solvent that must be sent offsite for recovery. They intend to do this by recovering the still bottoms generated by distillation of Freon/methyl chloroform waste. In addition, they eventually plan to phase out the use of methyl chloroform and methylene chloride and replace these materials with aqueous-based photoresist developers and strippers.

Facility D

Description

Facility D manufactures mobile communications equipment components in Florence, SC. The operation consists of a small metal-forming shop, prepaint and painting lines, electroplating, printed circuit board manufacture, and a 30,000 gpd onsite wastewater treatment plant.

Printed circuit boards are produced using the subtractive technique and solvent-based photoresists. Methylene chloride resist stripper and 1,1,1-trichloroethane (TCE) developer are continuously recycled in closed-loop stills. The TCE developer wastes (Waste Code F002) are recovered in a DuPont Riston SRS-120 solvent recovery still (referred to as the primary still) and returned to the developer line. Until recently, all still bottoms from the primary still were drummed and shipped offsite for reclamation at a solvent recycling facility. Facility D purchased a Recyclene Industries RX-35 solvent recovery system (referred to as the secondary still) in October 1985, to further remove TCE from still bottoms onsite.

The Recyclene Industries RX-35 solvent recovery system is a batch distillation system with a 30-gallon capacity, silicone oil immersion heated stainless steel boiler, a non-contact, water-cooled condenser, and a 10-gallon temporary storage tank. The boiler is equipped with a vinyl liner inside a Teflon bag. The Teflon bag provides temperature resistance and the vinyl bag collects solid residue, eliminating boiler clean-out and minimizing sludge generation after distillation. Two thermostats control the temperature of the boiler and the vapor, automatically shutting down the boiler when all the solvent has evaporated. The maximum operating temperature of the still is 370°F, so recovery of solvents with higher boiling points would not be practical. Recovery of a 20- to 25-gallon batch of still bottoms requires approximately 90 minutes at Facility D, and four to six batches are completed each day.

Results

Evaluation of the system consisted of the analysis of the contaminated feed, overhead product, and distillation bottoms. Based on a mass balance and analytical data, the following conclusions were made:

- Purity of recovered solvent was 99.9 percent;
- Total solvent recovery was 99.78 percent;
- Still bottoms contained 7.5 weight percent 1,1,1-trichloroethane; and
- Reduction in waste generation was 97.5 percent.

An additional objective of the study was to evaluate the economics of the batch solvent recovery unit. Annual cost savings (\$43,000) and waste reduction (110,602 gal) were calculated for Plant D, based on the first year of RX-35 operations. In addition, the investment payback period for the RX-35 was calculated considering credit for reclaimed solvent and reductions in waste transportation and disposal costs. The estimated payback period was 7.3 months, given the current level of solvent reclamation. Thus, the low capital cost of the unit and the relatively high costs of virgin solvent (\$4.50/gal) favor the second-stage recovery of TCE developer still bottoms.

There are several potential drawbacks to the implementation of RX-35 batch still that should be discussed. The first is that since the bottoms product contains 7.5 weight percent 1,1,1-TCE, it remains classified as RCRA Waste Code F002 (halogenated organic solvents) and is among those solvent wastes being considered under the land disposal ban. Thus, while this technology significantly reduces the volume and toxicity of the solvent still bottoms, it continues to generate a hazardous waste. A second potential concern is the accumulation of contaminants and/or breakdown products. For example, 6.7 to 11.0 percent concentrations of carbon tetrachloride were found in process feed and exit streams, indicating a build-up of this contaminant. Another significant contaminant found was 2-Butanone, which represents 3.6 percent of the solvent waste feed stream. It could not be determined whether a build-up of 2-Butanone was occurring or if it is harmful to the system. However, its presence and effect on the solvent properties of 1,1,1-TCE should be considered.

A final consideration in the implementation of any solvent recovery still is the issue of safety. The unit at Plant D was housed in a separate structure and provided with adequate ventilation to minimize the risk of exposure or explo-

sion. The RX-35, according to the manufacturer, is safe for flammable materials, and is rated for NFPA Class I, Division I, Group D environment. These safety considerations should help to minimize the risk of chronic exposure or danger from explosion to personnel. Nevertheless, explosion risks from solvent recovery operations should be carefully evaluated in planning the layout and installation of the unit.

Conclusions

The findings of the waste minimization case studies evaluated under this program are presented in Table 2, which includes data collected by the facilities and verified by sampling and laboratory results. These results indicate that a good variety of technologies exist to minimize metals-containing and solvent wastes produced by the printed circuit board and semiconductor industries. The technologies discussed range from simple changes in treatment system reagents with nominal capital costs to large onsite

solvent reclamation facilities with significantly higher capital costs.

Four of the case studies investigated under this program focused on technologies to reduce metal-plating rinsewater sludges. The use of SBH as a substitute for lime/ferrous sulfate was found to be viable in one case and appeared to be marginally acceptable in another. The case study on carbon adsorption recovery of plating bath wastes found that this technology significantly reduced both disposal costs and waste volume. The case study of electrolytic recovery indicated that this technology is highly waste stream specific. An acid copper electroplating rinse is an ideal waste stream for electrolytic recovery. However, other metal-bearing rinses, such as those from solder (tin/lead) plating or etching, are not appropriate for use of electrolytic recovery. Electrolytic recovery units are, however, generally inexpensive to purchase and can be used in many cases to supplement an end-of-pipe treatment process.

Two of the case studies presented in this Summary involve the recovery of

spent halogenated solvents using batch distillation units. Both case studies indicate that onsite solvent recovery is successful from a technical and an economic standpoint. In both cases, over 95 percent of the waste solvent was recovered and reused onsite. Solvent recovery appears to be a technology that could be applied to a number of printed circuit board manufacturing facilities.

The results of this project indicate that waste reduction can be achieved through the use of appropriate technology, and it can be achieved with significant reductions in cost. The case studies also indicate that the success of waste reduction is in many cases waste stream specific. The technologies will not necessarily be successful in all cases. A slight variation between one waste stream and another may make waste reduction either technically or economically impractical. Therefore, successful waste reduction is dependent on a thorough knowledge of waste quantities and characteristics.

Table 2. Summary of Findings of Waste Reduction Case Studies

Facility Name	Technology	Waste Reduction	Annual Waste Reduction Achieved	Capital Costs (\$)	Projected Annual Cost Savings (\$)
Facility A	Sodium borohydride reduction	Metals sludge	-- ^a	Nominal	-- ^b
Facility B	Sodium borohydride reduction	Metals sludge	962 tons	Nominal	115,870
Facility C	Solvent batch distillation	Methylene chloride Methyl chloroform Freon	6,152,000 gal	709,400	16,000,000
Facility D	2-Stage solvent distillation	1,1,1-Trichloroethane Resist developer still bottoms	10,625 gal	26,150	43,105
Facility E	Carbon adsorption plating bath reclamation	Plating bath wastes (metals sludge)	10,600 gal	9,200	57,267
Facility F	Agmet electrolytic recovery unit	Metals sludge	32 tons	30,350	(10,685) ^c

^aNot quantifiable, but a significant waste reduction was realized.

^bNot demonstrated during testing.

^c() indicates negative value.

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Harry M. Freeman is the EPA Project Officer (see below).

The complete report, entitled "Waste Minimization in the Printed Circuit Board Industry—Case Study," (Order No. PB 88-161 575/AS; Cost: \$19.95, 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 Officer can be contacted at:

*Hazardous Waste Engineering Research Laboratory
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