WASTE AUDIT STUDY

PRINTED CIRCUIT BOARD MANUFACTURERS

PREPARED FOR

TOXIC SUBSTANCES CONTROL PROGRAM

CALIFORNIA DEPARTMENT OF HEALTH SERVICES

PREPARED BY

PLANNING RESEARCH CORPORATION
SAN JOSE, CALIFORNIA

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WASTE AUDIT STUDY

OF THE

PRINTED CIRCUIT BOARD MANUFACTURING INDUSTRY

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ABSTRACT

This report presents the results of PRC's waste audit study for the printed circuit (PC) board manufacturing industry. The study was conducted to identify opportunities for waste reduction available to the PC board manufacturing industry and to develop a generic audit protocol that can be used by manufacturers to assess their own waste reduction opportunities. The study emphasized technologies available to small- and medium-sized PC board facilities. The tasks included in the study were: (1) selecting PC board manufacturing facilities to include in the study, (2) performing waste audits at each facility, (3) developing recommendations for implementing waste reduction technologies at each audited facility, (4) discussing with facility representatives the feasibility of implementing the waste reduction recommendations, and (5) developing this waste audit study report.

Three categories of waste reduction technologies are available to PC board manufacturers: (1) source reduction, (2) recycling and resource recovery, and (3) alternative treatment. The costs associated with implementing these technologies range from a few hundred dollars for simple improvements in housekeeping and minor process modifications to tens of thousands of dollars for installation of recovery or treatment units. The benefits realized from implementation include reductions in material purchase and waste disposal costs in addition to reduction in the liability associated with generating, handling and disposing hazardous wastes. A generic audit protocol has been developed as a result of the study and should be made available to the PC board manufacturing industry.

1989 REVISION

This revision of the original JUNE 1987 study report also includes the full report "Guide to Waste Minimization in the Printed Circuit Board Manufacturing Industry," prepared by Jacobs Engineering Group for the USEPA. This Jacobs/USEPA report was the result of the JUNE 1987 report being adapted by Jacobs to meet USEPA needs. This 1989 revision deletes those portions of the JUNE 1987 report that are covered in the Jacobs/USEPA report.

The Jacobs/USEPA report is included in APPENDIX A as a SUPPLEMENT. This revision also contains added APPENDIX E as listed in the CONTENTS.

DISCLAIMER

The information in this document has been funded wholly or in part by the United States Environmental Protection Agency under Contract 68-02-4286 to Radian Corporation. It has been subjected to the Agency's peer and administrative review and it has been approved for publication as an EPA Document.

This guide is advisory only. It is intended to provide guidance to printed circuit board manufacturers in developing approaches for minimizing wastes. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

The statements and conclusions of this document are those of the contractor and not necessarily those of the State of California. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed either as actual or implied endorsement of such products by the State of California.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Waste Minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act. This guide to waste minimization for the printed circuit board industry is the fourth of a series of seven manuals being developed to provide industry-specific information about hazardous waste minimization.

E. Timothy Oppelt, Director,
Risk Reduction Engineering Laboratory

ABSTRACT

This guide identifies and analyzes waste minimization methodologies appropriate for the printed circuit board manufacturing industry. The wastes resulting from printed circuit board manufacturing are associated with five types of processes: cleaning and surface preparation; catalyst application and electroless plating; pattern printing and masking; electroplating; and etching. The wastes themselves include airborne particulates, spent acids and alkaline solutions, spent solvents, spent plating baths, waste rinsewater, and other wastes. The guide also presents a set of detailed waste minimization assessment worksheets suitable for use by shop managers and engineers, or by outside consultants, to formulate a waste minimization strategy for the particular plant. Finally, case histories of waste minimization assessments performed at three plants are given.

Planning Research Corporation, San Jose, California, conducted the original California Department of Health Services (DHS) waste minimization assessments which are cited in this guide. Jacobs Engineering Group Inc., Pasadena, California edited and produced this version of the waste minimization assessment guide. Much of the information in this guide that provides a national perspective on the issues of waste generation and minimization for printed circuit board manufacturing was provided originally to the U.S. Environmental Protection Agency by Versar, Inc., and Jacobs Engineering Group in "Waste Minimization - Issues and Options, Volume II," report no. PB87-114369 (1986).

This report was submitted in fulfillment of Contract 68-02-4286 by Jacobs Engineering Group under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from January to June 1989, and work was completed as of July 1989.

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Many people contributed to and assisted in the development of this report. In particular, we wish to thank: David Leu, Benjamin Fries, Jan Radimsky, and Kim Wilhelm of the Alternative Technology Section of the California Department of Health Services, the owners and personnel of the printed circuit board manufacturing companies that participated in this study, and representatives of equipment manufacturers, chemical suppliers and hazardous waste recycle/disposal facilities who provided us with a great deal of cost and technical data.

This report was submitted in fulfillment of Contract No. 85-87160 by Planning Research Corporation under the sponsorship of the Department of Health Services. Work was completed as of June 10, 1987.

DISCLAIMER

The statements and conclusions of this report are those of the Contractor and not necessarily those of the State of California. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed either as actual or implied endorsement of such products.

REGULATORY CAVEAT

All text pertaining to law and regulations contained within this report are provided for general information only. That information is not reliable for use as a legal reference. The generator must contact the appropriate legal sources and regulatory authorities for up-to-date regulatory requirements, and their interpretation and implementation.

CONTRACTS

Contract No. 85-87160 provided $25,000 to prepare this report. No subcontractors were involved in the preparation.

Section One

INTRODUCTION

This guide is designed to provide printed circuit board manufacturers with waste minimization options appropriate for this industry. It also provides worksheets designed to be used for a waste minimization assessment of a manufacturing facility, to develop an understanding of the facility's waste generating processes and to suggest ways that the waste may be reduced.

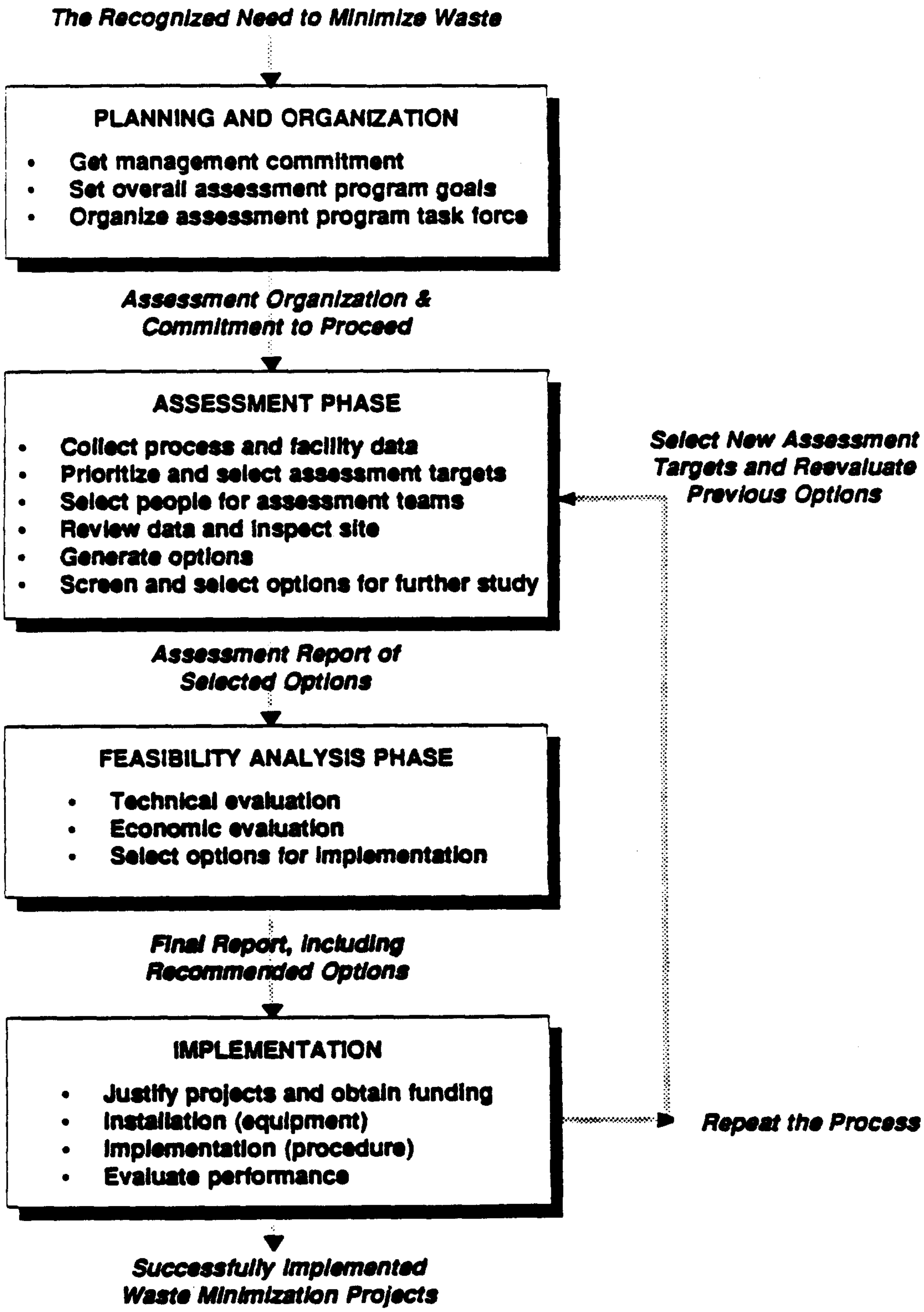
The worksheets and the list of waste minimization options were developed through assessments of three Santa Clara area prototype circuit board manufacturing shops. The assessments were commissioned by the California Department of Health Services (CDHS 1987). The firms' operations, manufacturing processes, and waste generation and management practices were surveyed, and their existing and potential waste minimization options were characterized. Economic analyses were performed on selected options.

Today's industry is faced with the major technological challenge of identifying ways to effectively manage hazardous waste. Technologies designed to treat and dispose of wastes are no longer the optimal strategy for handling these wastes for two major reasons. First, the potential liabilities associated with handling and disposing of hazardous wastes have increased significantly. Second, restrictions placed on land disposal of hazardous wastes have caused considerable increases in waste disposal costs. The economic impact of these changes is causing industry to explore alternatives to treatment and disposal technologies.

Waste minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act (RCRA). As the federal agency responsible for writing regulations under RCRA, the U.S. Environmental Protection Agency (EPA) has an interest in ensuring that new methods and approaches are developed for minimizing hazardous waste and that such information is made available to the industries concerned. This guide is one of the approaches EPA is using to provide industry-specific information about hazardous waste minimization.

EPA has also developed a general manual for waste minimization in industry. The *Waste Minimization Opportunity Assessment Manual* (USEPA 1988) tells how to conduct a waste minimization assessment and develop options for reducing hazardous waste generation at a facility. It explains the management strategies needed to incorporate waste minimization into company policies and structure, how to establish a company-wide waste minimization

Figure 1.1. The Waste Minimization Assessment Procedure



PLANNING AND ORGANIZATION

Essential elements of planning and organization for a waste minimization program are: getting management commitment for the program; setting waste minimization goals; and organizing an assessment program task force. The importance of these initial steps cannot be over estimated.

ASSESSMENT PHASE

The assessment phase involves a number of steps:

- o Collect process and facility data
- o Prioritize and select assessment targets
- o Select assessment team
- o Review data and inspect site
- o Generate options
- o Screen and select options for feasibility study

Collect process and facility data. The waste streams at a facility should be identified and characterized. Information about waste streams may be available on hazardous waste manifests, waste profile sheets, routine sampling programs and other sources.

Developing a basic understanding of the processes that generate waste at a facility is essential to the WMOA process. Flow diagrams should be prepared to identify the quantity, types and rates of waste generating processes. Also, preparing material balances for various processes can be useful in tracking various process components and identifying losses or emissions that may have been unaccounted for previously.

Prioritize and select assessment targets. Ideally, all waste streams in a facility should be evaluated for potential waste minimization opportunities. With limited resources, however, a plant manager may need to concentrate waste minimization efforts in a specific area. Such considerations as quantity of waste, hazardous properties of the waste, waste disposal restrictions, regulations, safety of employees, economics, cost of disposal, and other characteristics need to be evaluated in selecting a target stream.

Select assessment team. The team should include people with direct responsibility and knowledge of the particular waste stream or area of the plant, including machine operators and maintenance personnel.

Review data and inspect site. The assessment team evaluates process data in advance of the inspection. The inspection should follow the target process from the point where raw materials enter the facility to the points where products and wastes leave. The team should identify the suspected sources of waste. This may include the production process; maintenance operations; and storage areas for raw materials, finished product, and work in progress. The inspection may result in the formation of preliminary conclusions about waste minimization opportunities. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

Generate options. The objective of this step is to generate a comprehensive set of waste minimization options for further consideration. Since technical and economic concerns will be considered in the later feasibility step, no options are ruled out at this time. Information from the site inspection, as well as trade associations, government agencies, technical and trade reports, equipment vendors, consultants, and plant engineers and operators may serve as sources of ideas for waste minimization options.

Both source reduction and recycling options should be considered. Source reduction may be accomplished through:

- Good operating practices
- Technology changes
- Input material changes
- Product changes

Recycling includes:

- Use and reuse of waste
- Reclamation

Screen and select options for further study. This screening process is intended to select the most promising options for full technical and economic feasibility study. Through either an informal review or a quantitative decision-making process, options that appear marginal, impractical or inferior are eliminated from consideration. Some of the criteria used in screening options include impacts on product quality; employee safety; and environmental impacts of the alternatives.

FEASIBILITY ANALYSIS

An option must be shown to be technically and economically feasible in order to merit serious consideration for adoption at a facility. A technical evaluation determines whether a proposed option will work in a specific application. Both process and equipment changes need to be assessed for their overall effects on waste quantity, toxicity, and product quality. Also, any new products developed through process and/or raw material changes need to be tested for market acceptance.

An economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment, and net present value. As in any project, the cost elements of a waste minimization project can be broken down into capital costs and economic costs. Savings and changes in revenue also need to be considered.

IMPLEMENTATION

An option that passes both technical and economic feasibility reviews should then be implemented at a facility. It is then up to the WMOA team, with management support, to continue the process of tracking wastes and identifying opportunities for waste minimization throughout a facility and by way of periodic reassessments. Either such ongoing reassessments or an initial investigation of waste minimization opportunities can be conducted using this manual.

While it is difficult to quantify the future liability reduction that could result from implementing an option, this is an important factor in choosing a particular strategy, and should at least be discussed qualitatively in the evaluation.

References

CDHS. 1987. Waste Audit Study: Printed Circuit Board Manufacturers. Report prepared by Planning Research Corporation, San Jose, California, for the California Department of Health Services, Alternative Technology Section, Toxic Substances Control Division, April 1987.

USEPA. 1988. *Waste Minimization Opportunity Assessment Manual.* Hazardous Waste Engineering Research Laboratory (currently Risk Reduction Research Laboratory), Cincinnati, Ohio, EPA/625/7-88/003.

Section Two

PRINTED CIRCUIT BOARD MANUFACTURING INDUSTRY PROFILE

Manufacturers of printed circuit boards (PC boards) are included as part of the electronic component manufacturing industry. As of 1984, the printed circuit board manufacturing industry consisted of a total of 585 plants with an employment of 435,100 (NCO 1984). Industry personnel indicate that the actual number of plants may be closer to 1,000 (USEPA 1986).

The industry consists of large facilities totally dedicated to printed circuit boards, large and small captive facilities, small job shops doing contract work, and specialty shops doing low-volume and high-volume precision work. Approximately half of the printed circuit boards produced are by independent producers, while the rest are by captive producers. Over 65 percent of all printed circuit board manufacturing sites are located in the northeastern states and in California (NCO 1984).

The printed circuit board manufacturers visited as a part of this study are all considered small. Generally, these small companies can be characterized as those that produce up to 3,000 to 5,000 square feet of processed board each month and require approximately 8,000 to 10,000 square feet of building space. Large companies can be characterized as those that produce or 30,000 to 50,000 square feet per month.

Products and Their Use

Printed circuit boards can be classified into three basic types: single-sided, double-sided, and multi-layered. The total board production in 1983 was 14 million square meters (PEI 1983). Double-sided boards accounted for about 55 percent of the printed circuit boards produced, while multi-layer board production made up 26 percent (PEI 1983). The type of board produced depends on the spatial and density requirement, and on the complexity of the circuitry. Printed circuit boards are used mainly in the production of business machines, computers, communication equipment, control equipment and home entertainment equipment.

Raw Materials

The following raw materials are used by the industry (Stintson 1983, PEI 1983, Cox and Mills 1985):

Board materials	glass-epoxy, ceramics, plastic, phenolic paper, copper foil
Cleaners	sulfuric acid, fluoroacetic acid, hydrofluoric acid, sodium hydroxide, potassium hydroxide, trichloroethylene, 1,1,1-trichloroethane, perchloroethylene, methylene chloride
Etchants	sulfuric and chromic acid, ammonium persulfate, hydrogen peroxide, cupric chloride, ferric chloride, alkaline ammonia
Catalysts	stannous chloride, palladium chloride
Electroless copper bath	copper sulfate, sodium carbonate, sodium gluconate, Rochelle salts, sodium hydroxide, formaldehyde
Screen	silk, polyester, stainless steel
Screen ink	composed of oil, cellulose, asphalt, vinyl or other resins
Resists	polyvinyl cinnamate, allyl ester, resins, isoprenoid resins, methacrylate derivatives, poly-olefin sulfones
Sensitizers	thiazoline compounds, azido compounds, nitro compounds, nitro aniline derivatives, anthones, quinones, diphenyls, azides, xanthone, benzil
Resist solvents	ortho-xylene, meta-xylene, para-xylene, toluene, benzene, chlorobenzene, cellosolve and cellosolve acetate, butyl acetate, 1,1,1-trichoroethane, acetone, methyl ethyl ketone, methyl isobutyl ketone
Electroplating baths	copper pyrophosphate solution, acid-copper sulfate solution, acid-copper fluoroborate solution, tin-lead, gold, and nickel plating solutions
Resist stripping solutions	sulfuric-dichromate, ammoniacal hydrogen peroxide, metachloroperbenzoic acid, methylene chloride, methyl alcohol, furfural, phenol, ketones, chlorinated hydrocarbons, non-chlorinated organic solvents, sodium hydroxide

Process Description

Printed circuit (PC) boards, also called printed wiring boards, consist of patterns of conductive material formed onto a non-conductive base. The conductor is generally copper, although aluminum, chrome, nickel and other metals have been used. The metal is fixed to the base through use of adhesives, pressure/heat bonding, and sometimes screws. Base materials include pressed epoxy paper, phenolic, epoxy glass resins, teflon-glass, and many other materials.

There are three common types of PC boards: single-sided, double-sided, and multilayer. Single sided boards are those with a conductive pattern on one side only. Double-sided boards have conductive patterns on both faces. Multilayer boards consist of alternating layers of conductor and insulating material, bonded together. The conductors are connected together through plated-through holes.

Production methods that have been employed by the industry to produce printed circuit boards include subtractive processes and additive processes. Detailed descriptions of the process sequences are given elsewhere (Yapoujian 1982, Coombs 1979, USEPA 1979, PEI 1983). Because of the limitations of the additive processes, the subtractive method is currently the one most widely used, although it can produce more metal wastes than additive methods. The subtractive method is briefly described below for double-sided panels. Most of the operations shown are also common to the production of other types of printed circuit boards such as single-sided or multi-layered boards.

The conventional subtractive process employs a copper-clad laminate board composed of a non-conductive material such as glass epoxy or plastic. Printed circuit board manufacturers often purchase panels of board that are already copper clad from independent laminators. The manufacturing process consists of the following operations:

Board preparation - The process sequence begins with a baking step to ensure that the copper laminated boards are completely cured. Holes for the components are then drilled through stacks of boards or panels, often four layers thick. The drilling operation results in burrs being formed on one or both sides of the panel. These are removed mechanically through sanding and deburring steps to create an even surface.

Electroless copper plating - The smooth copper-clad board is subsequently electroless- plated with copper to provide a conducting layer through the drilled holes for circuit connections between the copper-clad board surfaces. Electroless plating involves the catalytic reduction of a metallic ion in an aqueous solution containing a reducing agent, resulting in deposition without the use of external electrical energy. The circuit board must be thoroughly cleaned before it is electroless-plated.

Materials typically used in the operation, that appear in the waste streams, include:

o Abrasive and alkaline cleaning compounds

- o Ammonium persulfate or peroxide-sulfuric acid etchant, for removing the oxidation inhibitor in the copper foil

- o Tin and palladium catalyst

- o Cupric chloride or copper sulfate plating bath containing formaldehyde or hypophosphate reducing agents, and amino acid, carboxylic acid, hydroxy acid, or amine chelating agents

- o Rinsewaters

Pattern printing and masking - Electroless plating with copper provides a uniform but very thin conducting layer over the entire surface, that has little mechanical strength. It is used initially, to deposit metal on non-conducting surfaces such as inside the holes. Electroplating is required to build up the thickness and strength of the conducting layers.

Pattern plating is one method of buiding up conducting layer thickness, and is the most common type of subtractive process used. It consists of electroplating only the insides of the holes and the circuit patterns. A layer of resist is deposited, using screen or photolithography techniques, in areas where electroplated conducting material is not desired. The layer of resist on these areas is later stripped off, and the copper foil is etched away.

The area where the resist has not been deposited constitutes the circuit pattern. These areas receive several electrodeposition layers. Tin/lead plating is one of the layers deposited, and it functions as another resist layer, allowing copper foil in the non-circuit areas to be etched away without the circuit pattern being damaged. The circuit pattern then receives final electroplated layers of metals such as nickel and gold. Chemicals used for these processes include:

- o Photo-sensitive inks (for silk screening circuit patterns onto the board)

- o Resists composed of epoxy vinyl polymers, halogenated aromatics, methacrylates, and/or polyolefin sulfones

- o Alkaline cleaners to remove residuals from pattern developing operations

- o Acid dips to remove oxides

- o Electroplating solutions typically containing copper, tin/lead, nickel and gold salts, cyanide, sulfate, pyrophosphate, and fluoroborate compounds

- o Etchants such as peroxide-sulfuric acid, sodium persulfate, ferric or cupric chloride, and chromic acid

Panel plating methods of PC board manufacture differ from pattern plating in that the entire board is electroplated with copper, including the holes, after which the non-circuit areas are etched away. Because of the additional copper deposited, panel plating can produce more metal wastes.

The *fully additive* method differs from the subtractive method described above in that it involves deposition of plating material onto the board only in the pattern dictated by the circuit, and does not require removal of the metal already deposited. The process begins with an unclad board. Plating resist is then applied onto the board in non-circuit areas. Electroless copper is subsequently deposited to build up the circuit to the desired thickness. Since the board doesn't initially have any copper in non-circuit areas, a copper etching step is thus eliminated, as well as much of the metal wastes.

Waste Description

There are five principal operations common to the production of all types of printed circuit boards. These include:

- Cleaning and surface preparation
- Catalyst application and electroless plating
- Pattern printing and masking
- Electroplating
- Etching

Typical waste streams generated from the unit operations in the printed circuit board manufacturing industry are listed in Table 2.1.

Airborne particulates generated from the cutting, sanding, routing, drilling, beveling, and slotting operations during board preparations are normally collected and separated using baghouse and cyclone separators. They are then disposed of, along with other solid wastes at landfills.

Acid fumes from acid cleaning and organic vapors from vapor degreasing are usually not contaminated with other materials, and therefore are often kept separate for subsequent treatment. The acid fume air stream is collected via chemical fume hoods and sent to a scrubber where it is removed with water. The scrubbed air then passes on to the atmosphere, and the absorbing solution is neutralized along with other acidic waste streams. Similarly, organic fumes are often collected and passed through a bed of activated carbon. The carbon bed is then regenerated with steam. In many cases, the regenerative vapor is condensed and the condensate containing water and solvents is drummed and sent for offsite treatments. In a few cases, the regenerative vapor is combusted in a closed fumes burner.

The spent acid and alkaline solutions from the cleaning steps are either contract hauled for off-site disposal or neutralized and discharged to the sewer. Spent chlorinated organic solvents are often gravity separated, and are recovered in-house or hauled away for reclaiming.

Table 2.1 Waste Streams from Printed Circuit Board Manufacturing

Waste Source	Waste Stream Description	Waste Stream Composition
Cleaning/Surface preparation	1. Airborne particulates 2. Acid fumes/organic vapors 3. Spent acid/alkaline solution 4. Spent halogenated solvents 5. Waste rinse water	Board materials, sanding materials, metals, fluoride, acids, halogenated solvents, alkali.
Catalyst application/ Electroless plating	1. Spent electroless copper bath 2. Spent catalyst solution 3. Spent acid solution 4. Waste rinse water	Acids, stannic oxide, palladium, complexed metals, chelating agents.
Pattern printing/masking	1. Spent developing solution 2. Spent resist removal solution 3. Spent acid solution 4. Waste rinse water	Vinyl polymers, chlorinated hydrocarbons, organic solvents, alkali.
Electroplating	1. Spent plating bath 2. Waste rinse water	Copper, nickel, tin, tin/lead, gold, fluoride, cyanide, sulfate.
Etching	1. Spent etchant 2. Waste rinse water	Ammonia, chromium, copper, iron, acids.

The remaining majority of the wastes produced are liquid waste streams containing suspended solids, metals, fluoride, phosphorus, cyanide, and chelating agents. Low pH values often characterize the wastes due to acid cleaning operations. The liquid wastes may be controlled using end-of-pipe treatment systems, or a combination of in-line treatment and separate treatment of segregated waste streams. A traditional treatment system for the wastes generated is often based on pH adjustment and the addition of chemicals that will react with the soluble pollutants to precipitate out the dissolved contaminants in a form such as metal hydroxide or sulfate. The solid particles are removed as a wet sludge by filtration or flotation, and the water is discharged to the sewer. The diluted sludge is usually thickened before dumping into landfills. Recent improvements in in-line treatment technologies such as reverse osmosis, ion exchange, membrane filtration, and advanced rinsing techniques increase the possibility for the recovery and reuse of water and metallic resources.

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Section Three

WASTE MINIMIZATION OPTIONS FOR PRINTED CIRCUIT BOARD MANUFACTURERS

This section discusses recommended waste minimization methods for printed circuit board manufacturers. These methods come from accounts published in the open literature and through industry contacts. The primary waste streams associated with manufacturing are listed in Table 3.1 along with recommended control methods. Many control measures associated with photoprocessing and cleaning wastes are not discussed in this report. The reader is referred to the appropriate reference material for information regarding these waste streams (USEPA 1989a, USEPA 1989b, USEPA 1986, CDHS 1986).

The waste minimization methods listed in Table 3.1 can be classified generally as source reduction, or recycling. Source reduction can be achieved through material or product substitution, process or equipment modification, or better operating practices. Recycling can include recovery of part of the waste stream or reuse of all of it, and can be performed on-site or off-site.

Better operating practices are procedural or institutional policies that result in a reduction of waste. They include:

- Waste stream segregation
- Personnel practices
  - Management initiatives
  - Employee training
  - Employee incentives
- Procedural measures
  - Documentation
  - Material handling and storage
  - Material tracking and inventory control
  - Scheduling

Table 3.1 Waste Minimization Methods for the Printed Circuit Board Industry

Operation	Waste Minimization Method
PC Board Manufacture	Product Substitution: Surface mount technology Injection molded substrate and additive plating
Cleaning and Surface Preparation	Materials substitution: Use abrasives Use non-chelated cleaners
	Increase efficiency of process: Extend bath life, improve rinse efficiency, countercurrent cleaning
	Recycle/reuse: Recycle/reuse cleaners and rinses
Pattern Printing and Masking	Reduce hazardous nature of process: Aqueous processable resist Screen printing versus photolithography Dry photoresist removal
	Recycle/reuse: Recycle/reuse photoresist stripper
Electroplating and Electroless Plating	Eliminate process: Mechanical board production
	Materials substitution: Non-cyanide baths Non-cyanide stress relievers
	Extend bath life: reduce drag-in Proper rack design/maintenance, better precleaning/rinsing, use of demineralized water as makeup, proper storage methods
	Extend bath life: reduce drag-out Minimize bath chemical concentration, increase bath temperature, use wetting agents, proper positioning on rack, slow withdrawal and ample drainage, computerized/automated systems, recover drag-out, drain boards
	Extend bath life: maintain bath solution quality Monitor solution activity. Control temperature. Mechanical agitation. Continuous filtration/carbon treatment. Impurity removal

Continued on next page

Table 3.1 Waste Minimization Methods for the Printed Circuit Board Industry

(continued)

Operation	Waste Minimization Method
Electroplating and Electroless Plating (continued)	Improve rinse efficiency: Closed-circuit rinses. Spray rinses. Fog nozzles. Increased agitation. Countercurrent rinsing. Proper equipment design/operatnon. Deionized water use.
	Recovery/reuse: Segregate streams. Recover metal values
Etching	Eliminate process: Differential plating
	Materials substitution: Non-chelated etchants. Non-chrome etchants
	Increase efficiency: Use thinner copper cladding. Pattern vs. panel plating. Additive vs. subtractive method.
	Reuse/recycle: Reuse/recycle etchants
Wastewater Treatment	Reduce hazardous nature: Alternative treatment chemicals that generate less sludge Use of ion exchange and activated carbon for recycling wastewater
	Reuse/recycle: Waste stream segregation

- Loss prevention practices
  - Spill prevention
  - Preventive maintenance
  - Emergency preparedness

- Accounting practices
  - Apportion waste management costs to departments that generate the waste

Better operating practices apply to all waste streams. In addition, specific better operating practices that apply to certain waste streams are identified in the appropriate sections that follow.

Product Substitution

While not under the control of most printed circuit board manufacturers, improvements in the techniques used in the packaging of microchips can result in a decrease of waste associated with printed circuit board manufacturing. Two new techniques include:

Increased use of surface mount technology. Presently, the dual-in-line package (DIP) accounts for 80% of all packaging of integrated circuits (Bowlby 1985). More efficient packages, however, are being developed which utilize a relatively new method of attaching packages to printed circuit boards. One important method is called surface mount technology (SMT). The use of SMT instead of the conventional through-hole insertion mounting allows for closer contact areas of chip leads, and therefore reduces the size of printed circuit boards required for a given number of packages or DIPS. For a fixed number of packages, the printed circuit board needs to be only 35 percent to 60 percent as large as a printed circuit board designed for the old style package (Bowlby 1985). As the metal area on which cleaning, plating and photoresist operations are performed is decreased, the wastes associated with these operations can also be reduced. At present, however, SMT uses considerably higher quantities of chlorofluorocarbons for degreasing than through-hole mounting. CFC-113 is one of the major degreasing agents in current use. Because of the danger that some chlorofluorocarbons present to the atmospheric ozone layer, the overall environmental risks of SMT must be carefully examined, and alternative degreasing solvents identified, before replacing through-hole technology with SMT.

Use of injection molded substrate and additive plating. The development of high-temperature, high-performance thermoplastics has introduced the use of injection molding into the manufacturing of printed circuit boards. In this process, heated liquid polymer is injected under high pressure into precision molds. Since the molded substrates are unclad, semi-additive or fully additive plating is used to produce metalized conductor patterns (Engelmaier and Frisch 1982). Injection molding, coupled with a fast-rate electrodeposition (FRED) technique, such as that developed by Battelle (LWVM 1985), can be used to manufacture complex three-dimensional printed circuit boards with possible reduction in hazardous waste generation due to the elimination of spent toxic etchants.

Cleaning and Surface Preparation

As mentioned in the introduction, the reader should refer to the appropriate reference material (USEPA 1989, CDHS 1986) for information regarding the reduction of waste associated with parts cleaning. Information is provided below on: abrasive cleaning; use of non-chelated cleaning chemicals; extending bath life and improving rinse efficiency; use of countercurrent cleaning arrangements; and reuse/recycle of cleaning agents and rinse water.

USE ABRASIVE INSTEAD OF AQUEOUS CLEANING

Mechanical cleaning methods offer an alternative to aqueous techniques and generate less hazardous waste; however, these methods can only be employed before electronic components have been added to the boards. Abrasive blast cleaning uses plastic, ceramic, or harder media such as aluminum oxide to remove oxidation layers, old plating, paint and burrs from workpieces, and to create a smooth surface. The aim is to select a blast medium that is harder than the layer to be stripped, but softer than the substrate, in order to prevent damage to the part. Abrasives can also be used in vibratory cleaning (in which parts are immersed in a vibrating tank containing abrasive material and water), in tumbling barrels, or applied via a buffing wheel. More information on abrasive cleaning, particularly tumbling barrels and vibratory cleaning, can be found in Durney (1984) and ASM (1987).

USE NON-CHELATED CLEANING CHEMICALS

The use of non-chelate process chemicals instead of chelated chemical baths can reduce hazardous waste generation. Chelators are employed in chemical process baths to allow metal ions to remain in solution beyond their normal solubility limit. This enhances cleaning, metal etching, and selective electroless plating (Couture 1984). Once the chelating compounds enter the waste stream, they inhibit the precipitation of metals, and additional treatment chemicals must be used. These treatment chemicals end up in the sludge and contribute to the volume of hazardous waste sludge.

Ferrous sulfate is a common reducing agent used to treat wastewaters that contain chelators. The ferrous sulfate breaks down the complex ion structures to allow metals to precipitate. However, the iron added to the treatment process also precipitates as a metal hydroxide. Since enough ferrous sulfate is usually added to the wastewater to achieve an iron to metal ratio of 8:1, a significant additional volume of sludge is generated (Couture 1984). One printed circuit board manufacturer visited during the audit study used ferrous sulfate to break down chelators prior to metals precipitation. The iron present in the resultant sludge contributed approximately 32 percent of the total dry weight of the sludge.

Common chelators used in printed circuit board manufacturing chemicals include ferrocyanide, ethylenediaminetetraacetic acid (EDTA), phosphates, and ammonia (Foggia 1987). Chelating agents are commonly found in cleaning chemicals and etchants. Non-chelate alkaline cleaners are available; however, laboratory tests have shown that some of these products still have the ability to chelate metals (Couture 1984).

In addition to using non-chelated chemistries, the use of mild chelators can also reduce the need for additional treatment of wastewaters. Mild chelators are less difficult to break down. Therefore, metals can be precipitated out of solution during treatment without using the volume of treatment chemicals that is often necessary with strong chelators. For example, EDTA is a mild chelator that only requires lowering the pH to below 3.0 to allow metals to precipitate (Foggia 1987).

One disadvantage of using non-chelated process baths is that they usually require continuous filtration to remove the solids that form in the bath. The costs of these filter systems range from approximately $400 to $1,000 for each tank using a non-chelated process chemistry. These systems generally have a 1 to 5 micron filter with a control pump that can filter the tank contents once or twice each hour (Foggia 1987). In addition to the purchase and setup costs, filter replacement and maintenance costs are incurred when this system is used.

EXTEND BATH LIFE AND IMPROVE RINSE EFFICIENCY

This method applies to nearly any tank of processing solution used in the facility. See the discussion of electroplating waste reduction methods for detailed information.

USE COUNTERCURRENT CLEANING ARRANGEMENT

A common hazardous waste stream generated by printed circuit board manufacturers is waste nitric acid from the cleaning of electroplating workpiece racks. Typically, racks are placed in a nitric acid bath to clean off the plated copper. When the copper content in the bath gets too high to effectively clean the racks, the nitric acid is containerized for disposal. Use of a cascade cleaning system can significantly reduce nitric acid waste generation.

During the audits, one small printed circuit board manufacturer who operated a five tank plating rack cleaning line generated approximately 15 gallons of waste nitric acid in 6 months compared to another small company that used a single tank for cleaning racks and generated approximately 60 gallons each month. Both companies operate similar size process lines, and are considered small printed circuit board manufacturers (both estimated their printed circuit board production to be 3,000 square feet per month). Assuming that waste disposal for the spent nitric acid is $50 per 55-gallon drum and the cost of technical grade nitric acid is approximately $3.50 per gallon, the differential operating costs are $3042 per year (excluding differences in labor-increased rack handling versus decreased waste handling). The total cost of adding four additional tanks to the one-cleaning-tank line would be $1620.

REUSE/RECYCLE OF CLEANING AGENTS

Peroxide/sulfuric acid solution is used as a mild etchant for cleaning copper and removing oxides prior to plating. When the solution is brought off-line and cooled, the copper crystallizes as copper sulfate. The supernatant can then be returned to the tank, replenished with oxidizers, and reused. The copper sulfate crystals can be used as copper crystallizes as copper sulfate. The supernatant can then be returned to the tank, replenished with oxidizers, and reused. The copper sulfate crystals can be used as copper electroplating bath makeup (Couture 1984). The practice is only advisable, however, if the crystals are first dissolved into solution and treated with activated carbon to remove the organics. Otherwise, the organics present in the crystals could ruin the plating bath.

In addition to recovering metals from the spent bath, spent acid can be regenerated by means of ion exchange (Basta 1983). Eco-Tec Ltd., in Ontario, Canada, markets an acid purification system that employs a proprietary resin that recovers mineral acids. The metals are recovered in a concentrated (but still dissolved) form. The concentrated metals can then be recovered by electrolytic means.

Ion exchange is employed by Modine Manufacturing, in Trenton, Mo., to treat copper-contaminated sulfuric acid/hydrogen peroxide solution which is used to brighten brass (Basta 1983). Sodium phosphate salts, formed in nickel/copper electroless plating, can be converted into useful hypophosphite salts by ion exchange resins activated with hypophosphorous acid. The use of ion exchange resins for regeneration, however, suffers from the disadvantage of generating additional wastes, such as spent resins and resin regeneration solutions.

REUSE/RECYCLE OF RINSE WATER

After rinse solutions become too contaminated for their original rinse process, they may be useful for other rinse processes. For example, rinses containing high levels of process chemicals can be concentrated through evaporation and returned to the process baths as makeup. Closed-circuit rinsing of this type can dramatically reduce the hazardous chemicals content of the waste stream.

Effluent from a rinse system that follows an acid cleaning bath can be reused as influent water to a rinse system following an alkaline cleaning bath. If both rinse systems require the same flow rate, 50 percent less rinse water would be used to operate them. In addition, using the effluent from the rinse solution that follows an acid cleaning process as the feed to the rinse system that follows an alkaline cleaning process rinse system can actually improve rinse efficiency for two reasons. First, the chemical diffusion process is accelerated because the concentration of alkaline material at the interface between the drag-out film and the surrounding water is reduced by the neutralization reaction. Second, the neutralization reaction reduces the viscosity of the alkaline drag-out film (USEPA 1982a). One successful example of this technique was observed in a nickel plating process in which the same rinse water stream was used for the rinses following the alkaline cleaning, acid dip, and nickel plating tanks. Instead of having three different rinse streams, only one stream was used, greatly reducing the overall rinse water requirements (USEPA 1983). Adding acid rinses to alkaline rinses can result in problems, however. Unwanted precipitation of metal hydroxides onto the cleaned workpieces can occur in some instances. Before being implemented, a combined acid and alkaline rinse system must be thoroughly investigated in the particular environment of the process line.

Other rinse water recycling opportunities are also available. Acid cleaning rinse water effluent can be used as rinse water for workpieces that have gone through a mild acid etch rinse efficiencies. The water from fume scrubbers has been shown to be practical for rinsing in certain cases (Cheremisinoff, Peina, and Ciancia 1976). Spent cooling water or steam condensate can also be employed for rinsing if technically permissible and economically justified. Printed circuit board manufacturers should evaluate the various rinse water requirements for their process lines and configure rinse system arrangements that take advantage of rinse water reuse opportunities.

Pattern Printing and Masking

Many of the source reduction techniques discussed for the photoprocessing industry (USEPA 1988) apply to this phase of printed circuit board manufacturing. Listed below are several techniques that deal with circuit board fabrication.

Use aqueous processable resist instead of solvent processable resist. Aqueous processable resists (such as the Du Pont Riston photopolymer film resists which allow for the use of caustic and carbonates as developer and stripper) can be used in place of solvent processable resists whenever possible to eliminate the generation of toxic spent solvents. Hundred of facilities are now employing these aqueous processable films for the manufacturing of printed circuit boards.

Use screen-printing instead of photolithography to eliminate the need for developers. Screen-printing has conventionally been used only to produce printed circuit boards which require very low resolution in the width and spacing of the circuit lines. Some companies have recently developed screen-printing techniques which can provide higher degrees of resolution. For example, General Electric has developed a method for screen-printing down to 0.01 inch resolution which can be used to manufacture printed circuit boards for appliances (Greene 1985). The majority of printed circuit board manufacturers, however, are still using the photolithographic technique for printed circuit boards having circuitry finer than 12 mil lines and spaces.

Use Asher dry photoresist removal method to eliminate the use of organic resist stripping solutions. Although this method is increasingly popular in the semiconductor industry, its use has not been reported by printed circuit board manufacturers, probably because the printed circuit board resists are usually much thicker than the corresponding semiconductor resist layers.

Recycle/reuse photoresist stripper. Photoresist stripper is used to remove photoresist material from the board. This photoresist is a polymer material that remains in the stripper tank in small flakes that slowly settle to the bottom. When the sludge formed at the bottom of the stripper tank builds up, the flakes begin to adhere to circuit boards and the stripper solution is considered spent. Increased use of the solution can be achieved by decanting and filtering the stripper solution out of the tank into a clean tank. This is feasible because the stripper usually becomes spent as a result of the residue buildup long before it becomes spent as a result of a decrease in chemical strength.

Electroplating and Electroless Plating

Source reduction methods associated with electroplating and electroless plating center around eliminating the need for the operation, reducing the hazardous nature of the materials used, extending process bath life, improving rinse efficiency, and recovering/reusing spent materials.

ELIMINATE NEED FOR OPERATION

Use mechanical board production methods/systems. For facilities that produce low-volume prototype circuit boards, mechanical board production systems are available which bypass all operations involving chemicals. Circuit boards are designed on a computer and the pattern is then etched by means of a mechanical stylus on a copper-clad board. While this system is not viable for producing boards in large quantities, it is highly suited for use in development/research settings.

REDUCE HAZARDOUS MATERIALS USED

Use non-cyanide plating baths.

Use non-cyanide stress relievers. In the case of electroless copper plating, water soluble cyanide compounds of many metals are typically added to eliminate or minimize the internal stress of the deposit. It has been found that polysiloxanes are also effective stress relievers (Durney 1984). By substituting polysiloxanes for cyanides, the hazardous nature of the spent bath solution can be reduced.

EXTEND PROCESS BATH LIFE

Process baths may contain high concentrations of heavy metals, cyanides, solvents and other toxic constituents. They are not discarded frequently but rather are used for long periods of time. Nevertheless, they do require periodic replacement due to impurity build-up resulting from drag-in or decomposition and the loss of solution constituents by drag-out. When a solution is contaminated or exhausted, the resulting waste solution may contain high concentrations of toxic compounds and require extensive treatment. The source control methods available for extending process bath life include reducing or removing impurities formed in the bath, reducing the loss of solution (drag-out) from the bath, and maintaining bath solution quality.

Reduce Impurities

Impurities come from five sources: racks, anodes, drag-in, water or chemical make-up, and air. The buildup of impurities can be limited by the following techniques:

Proper rack design and maintenance. Corrosion and salt buildup deposits on the rack elements contaminate solutions if they chip away or fall into the solution. Proper design and regular cleaning will minimize this form of contamination. Fluorocarbon coatings applied to the racks have also been found to be effective (Lane 1985). Such a coating lowers drag-out as well since less bath solution remains in the corroded crevices on the racks or barrels.

Use purer anodes and anode bags. During the plating process, metal from the anode dissolves in the plating solution and deposits on the cathode (workpiece). Some of the impurities contained in the original anode matrix stay behind in the plating solution, eventually accumulating to prohibitive levels. Thus, the use of purer metal for the anode extends the plating solution life. Anode bags can also be used to prevent pieces of decomposed anodes from falling into the tank.

Drag-in reduction by better rinsing. Efficient rinsing of the workpiece between different process baths reduces the drag-in of plating solution into the next process bath.

Use of deionized or distilled make-up water. To compensate for evaporation, water is required for makeup of plating solutions. Using deionized or distilled water is preferred over tap water, since tap water may have a high mineral or solids content, which can lead to impurity buildup.

Proper storage of chemicals. Proper storage of the process solutions can also reduce waste generation. Usually, the process solutions are stored as a two-part solution and are mixed when a batch is needed. Prolonged storage of mixed solutions may allow some chemical reactions to occur that could generate contaminants that reduce bath life. In electroless copper plating, if formaldehyde (a reducing agent) is stored with a hydroxide, the hydroxide can cause the formaldehyde to break down into formic acid and methyl alcohol. Thus, it is better to only store non-reactive mixtures of materials or to store each item separately.

Once you have reduced impurity buildup in the bath, you need to concentrate on reducing solution losses through drag out.

Reduce Drag-Out

Several factors contribute to drag-out. These include workpiece size and shape, viscosity and chemical concentration, surface tension, and temperature (USEPA, 1982a). By reducing the volume of drag-out that enters the rinse water system, valuable process chemicals can be saved and sludge generation can be reduced. More discussion of the impact on sludge generation due to drag-out is presented under "alternative treatment methods."

During the course of this study, it was found that most printed circuit board manufacturers have little idea of the volume of drag-out their various process lines generate. Process chemical suppliers assess drag-out using a standard rate of 10 to 15 ml/ft^2 of circuit board (Foggia 1987). However, this standard rate does not take into account the various process bath operating parameters that can be used or the effects of various workpiece rack withdrawal methods. Nevertheless, this standard drag-out rate is a good starting point for determining the impact of drag-out on waste generation. Factors affecting drag-out are described in Table 3.2.

Table 3.2 Factors That Increase the Amount of Drag-Out

High surface tension
Highly viscous plating solution
Larger workpiece size
Faster workpiece withdrawal
Shorter drainage time
Orientation of workpiece during removal so that drainage is reduced

Generally, drag-out minimization techniques include:

Minimize bath chemical concentration. Controlling the chemical concentration of the process bath can reduce drag-out losses in two ways. Reducing toxic chemical concentrations in a process solution reduces the quantity of chemicals and the toxicity in any dragout that occurs. Also, greater concentrations of some of the chemicals in a solution increase the viscosity (USEPA 1982a). As a result, the film that adheres to the workpiece as it is removed from the process bath is thicker and will not drain back into the process bath as quickly. Therefore the volume of drag-out loss is increased and a higher chemical concentration in the drag-out is created. In electroless copper plating for printed circuit board manufacture, dilute solutions have been tried successfully by many manufacturers (USEPA 1981).

Chemical product manufacturers may recommend an operating concentration that is higher than necessary to perform the job. A printed circuit board manufacturer should determine the lowest process bath concentration that will provide adequate product quality. This can be done by mixing a new process bath at a slightly lower concentration than normal. As fresh process baths are mixed the chemical concentration can continue to be reduced until product quality begins to be affected. At this point, the manufacturer can identify the process bath that provides adequate product quality at the lowest possible chemical concentration.

Fresh process baths can often be operated at lower concentrations than used baths. Makeup chemicals can be added to the used bath to gradually increase the concentration. This procedure allows newer baths to be operated at lower concentrations and older baths to be maintained for longer periods of time before requiring disposal.

Increase bath operating temperature in order to lower viscosity. Increased temperature lowers both the viscosity and surface tension of the solution, thus reducing drag-out. The resulting higher evaporation rate may also inhibit the carbon dioxide absorption rate, slowing down the carbonate formation in cyanide solutions. Unfortunately, this benefit may be lost due to the formation of carbonate by the breakdown of cyanide at elevated temperatures. Additional disadvantages of this option would include higher energy costs, higher chance for contamination due to increased make up requirement, and increased need for air pollution control due to the higher evaporation rate.

Use wetting agents. Wetting agents can be added to a process bath to reduce the surface tension of a solution and, as a result, reduce the volume of drag-out loss. The use of wetting agents in the metal finishing industry has been estimated to reduce drag-out loss by as much as 50 percent (USEPA, 1982a). However, most printed circuit board manufacturers prefer using process chemicals that are free of wetting agents because they can create foaming problems in the process baths. Although the process bath chemistries of a printed circuit board manufacturing line may not always allow the addition of wetting agents, their use should be evaluated.

Position workpiece properly on the plating rack. When a workpiece is lifted out of a plating solution on a rack, some of the excess solution on its surface (drag-out) will drop back into the bath. Proper positioning of the workpiece on a rack will facilitate maximum drainage of drag-out back into the bath. The position of any object which will minimize the carry-over of drag-out is best determined experimentally, although the following guidelines were found to be effective (USEPA 1981):

- Orient the surface as close to vertical as possible.
- Rack with the longer dimension of the workpiece horizontal.
- Rack with the lower edge tilted from the horizontal so that the runoff is from a corner rather than an entire edge.

While positioning of the printed circuit board offers little variability -- the boards are generally placed upright in a rack -- a board that is tilted at an angle, allowing it to drip down onto an adjacent board instead of directly into the bath, may lead to increased drag-out loss. The operator must ensure that the workpiece is positioned properly to prevent unnecessary drag-out loss.

Withdraw boards slowly and allow ample drainage. The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that it is believed that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only (USEPA, 1982a). However, since workpieces are usually removed from a process bath manually, it is difficult to control the speed at which they are withdrawn. Nevertheless, supervisors and management should emphasize to process line operators that workpieces should be withdrawn slowly.

Workpiece drainage once the part is removed from the bath also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath area and place it in the rinse tank. However, installation of a bar or rail above the process tank, and the requirement that all workpieces be hung from it for at least 10 seconds, may help ensure that adequate drainage time is provided prior to rinsing. Printed circuit board manufacturers express concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Although some process steps may not be amenable to these drag-out reduction techniques, increased workpiece rack removal and drainage time can still be effective for many process steps.

Use computerized/automated control systems. Computerized process-control systems can be used for board handling and process bath monitoring to prevent unexpected decomposition of the plating bath. Since the use of a computerized control system not only requires a large capital outlay for initial installation but also increases the demand for skilled operations and maintenance personnel, only very large companies which manufacture both printed circuit boards and other electronic components are incorporating this change in their manufacturing process. For example, Hewlett-Packard in Sunnyvale, California reported its successful use of computers for plating operations on printed circuit boards (Anonymous 1983).

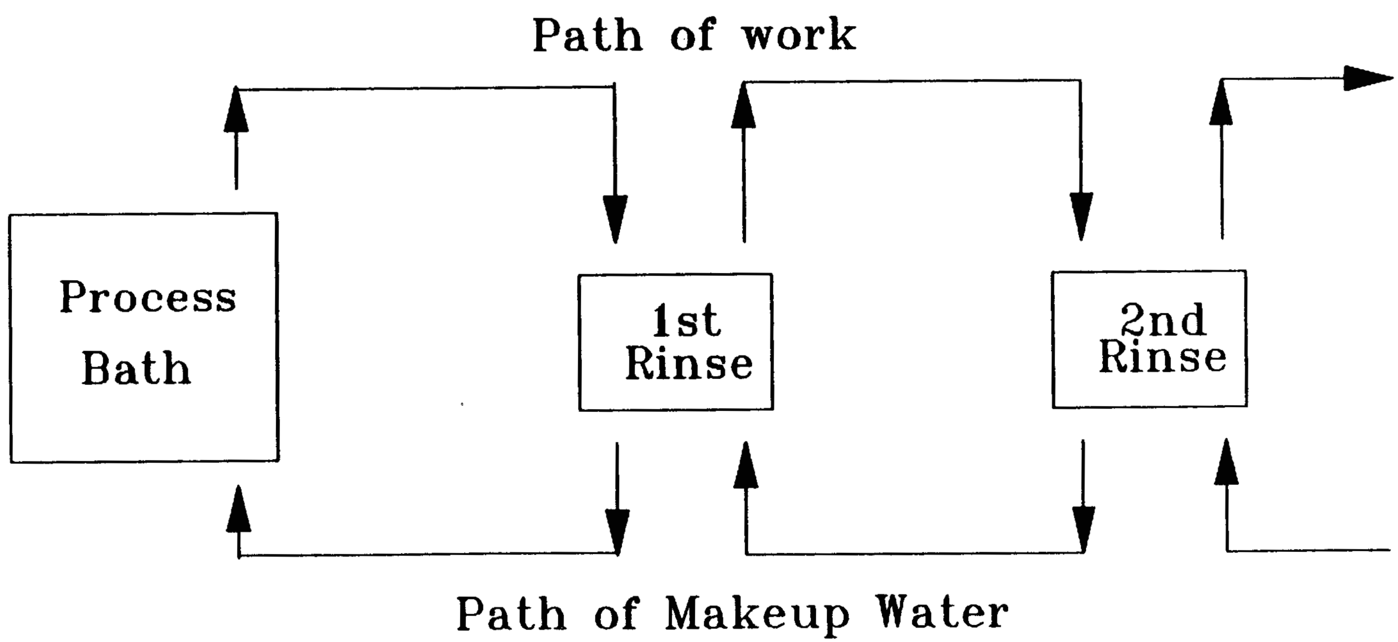
Recover drag-out from baths. In addition to reducing the volume of drag-out that is lost from the process bath, printed circuit board manufacturers can recover drag-out losses by using drain boards and close-circuit rinsing. Drain boards are used to capture process chemicals that drip from the workpiece rack as it is moved from the process bath to the rinse system. The board is mounted at an angle that allows the chemical solution to drain back into the process bath. Drainage boards should be installed if there is space between the process bath tank and the rinse tank where chemical solutions would otherwise drip onto the floor and enter the wastewater system when the floor is washed down.

Another method of reducing drag-out loss is to recover it for reuse in the process tank. The most common way to do this is through use of drag-out tanks (also called still or dead rinses). Drag-out tanks can be used to capture process chemicals that adhere to the circuit board and return them to the process bath. Drag-out tanks are essentially rinse tanks that operate without a continuous flow of feed water. Chemical concentrations in these tanks increase as more workpieces are passed through. Since there is no feed water flow to cause rinse water turbulence, air agitation is often used to enhance rinsing. After a period of time, the concentration of the drag-out tank solution will increase to the point where it can be used to replenish the process bath. Drag-out tanks are primarily used with process baths that operate at an elevated temperature. The high temperature causes evaporative water losses that can be compensated for by adding the drag-out tank solution back to the process bath. If the evaporation rate of the process tank is not high enough, evaporators can be installed on it. They can also be installed on the drag-out tank, to further concentrate the rinse solution to be used as makeup.

Closed-circuit rinse systems can employ continuously flowing rinses as well as static rinses that are periodically added as makeup to the process bath. Often, two or more rinses are used in a counter-current arrangement such as is illustrated in Figure 3.1. In this arrangement, the work is first rinsed in the least clean rinse bath, and then in successively cleaner baths. Spent rinse water from the cleanest bath gets added to the next cleanest bath, and eventually to the process bath itself. The use of closed-circuit rinses can be very significant in reducing the amount of heavy metal wastes and other hazardous chemicals in the waste streams (Meltzer 1989).

The printed circuit board manufacturing companies visited during this study all used drag-out tanks, but none of them used the drag-out solution to replenish the process bath. Instead, these companies dumped the solutions into their treatment systems. They are reluctant to reuse the drag-out solution because of fear of contamination. Since a drag-out tank can often be used for more than a week between dumps and because the tank is uncovered, operators are concerned that someone could improperly use the tank to rinse a workpiece; the contaminated drag-out solution would then contaminate the process bath when used to replenish the process tank. Also, some process bath chemistries are such that

FIGURE 3.1
MULTIPLE CLOSED CIRCUIT
COUNTERFLOW RINSE SYSTEM



adding drag-out solution back into the process tank would spoil the bath. For example, electroless copper baths contain chemicals that break down in a diluted drag-out solution. If the solution is then added back to the process tank, these breakdown chemicals could adversely affect the electroless copper bath (Stone 1987). If the potential for contamination or deterioration of the drag-out solution can be overcome, however, drag-out tanks can be used on copper and tin/lead electroplating lines.

Maintain Bath Solution Quality

Once the amount of drag-in and drag-out from the process bath has been reduced, attention should focus on ways to maintain the bath at optimum operating conditions. Many facilities rely on drag-out from the bath as the way of purging impurities that would otherwise build up and interfere with operation. From an environmental viewpoint, this is a poor technique since it does not directly address the issue of impurity formation, results in high losses of valuable process solutions, and moves the problem downstream to the treatment unit.

The following methods are noted as ways of increasing bath life and minimizing the impact on existing treatment systems:

Monitor solution activity. By frequent monitoring of the bath activity and regular replenishment of reagents or stabilizers, bath life can be prolonged (Durney 1984). These reagents or stabilizers differ from process to process. Stabilizers such as 2-mercaptobenzothiozole and methanol are found effective in electroless copper plating used for manufacturing printed circuit boards. The addition of stabilizers can sometimes decrease the deposition rate, but can still be economical in the long run.

Control bath temperature. Good control of the bath temperature is important from the viewpoint of performance predictability and is another method of prolonging bath life. Many surface treatment operations use tanks with immersed cooling/heating coils. As the salts precipitate and form scales on the coils the heat transfer is impeded and temperature control becomes increasingly difficult. Heat transfer efficiency can be maintained by periodic cleaning of the coils or by using jacketed tanks instead of coils.

Use mechanical agitation. Many process baths employ air agitation to increase and maintain the efficiency of the bath. This practice can introduce contaminants into the bath. The two principal contaminants are oil from the compressor or blower and carbon dioxide. The oil will lead to undue organic loading while the carbon dioxide can lead to carbonate buildup in alkaline baths. A viable alternative is to use mechanical agitation.

Use continuous filtering/carbon treatment. To avoid surface roughness in the plating resulting in high reject rates, baths should be continuously filtered to remove impurities. The flow rate to the filter should be as high as practical to prevent particles from settling on the parts. Since filters can seldom remove solids at the same rate that they are introduced by way of drag-in, filtering should be performed even when the bath is not in use. Install as coarse a filter as practical, since coarse filters allow higher loading before requiring replacement, allow for higher flow rates and hence greater tank turn-overs, and require less servicing. When organic buildup is a problem, use of carbon filter cartridges is appropriate.

Regenerate solution through impurity removal. There are methods that have been successfully used to increase the longevity of plating solutions through impurity removal. More efficient filtering of a plating solution has kept levels of impurities low and extended solution life (McRae 1985). Metallic salts can sometimes be removed by temporarily lowering the bath temperature so as to form solid crystals. In the case of electroless nickel plating, the sodium sulfate that forms can be crystallized by lowering the bath temperature to 41-50°F (Durney 1984). The crystals can then be removed by filtration.

IMPROVE RINSE EFFICIENCY

Most hazardous waste from a printed circuit board manufacturing plant comes from the treatment of wastewater generated by the rinsing operations that follow cleaning, plating, stripping, and etching processes (Couture 1984). Three basic strategies are used to provide adequate rinsing between various process bath operations. These are (1) turbulence between the workpiece and the rinse water, (2) sufficient contact time between the workpiece and the rinse water, and (3) sufficient volume of water during contact time to reduce the concentration of chemicals rinsed off the workpiece surface (USEPA 1982a). The third strategy is most commonly employed by printed circuit board manufacturers. Reliance on this strategy causes printed circuit board manufacturers to use significantly more rinse water than is actually required (Couture 1984).

Many techniques are available that can improve the efficiency of a rinsing system and reduce the volume of rinse water used. These techniques include:

Use of closed-circuit rinses. As mentioned above, installing one or more closed-circuit still or counter-flow rinsing tanks immediately after a plating bath allows for metal recovery and lowered rinse water requirements. The contents of the rinses are used to replenish the upstream plating bath. As previously mentioned, a major problem with the use of still rinses is that while they are commonly installed at many plants, operators typically do not return the solution to the bath due to concern over solution contamination.

Generally, the use of a drag-out or still rinse tank can reduce both rinse water usage and chemical losses by 50 percent or more (USEPA 1982a). Assuming that a chemical bath processes 3,000 square feet of board each month, the total volume of process bath drag-out loss each month would be 12 gallons, with a drag-out rate of 15 ml/square foot of board. If the rinse system following the process bath operates at a flow rate of 10 gpm for a total of two hours each day, water usage would be 24,000 gallons per month based on 20 work days per month. A 50 percent reduction in process bath chemical loss and water usage achieved by installing a drag-out tank would reduce process bath losses by six gallons per month and water usage by 12,000 gallons.

Use spray rinsing. Although spray rinsing uses between one-eighth and one-fourth the volume of water that a dip rinse uses (USEPA 1982a), it is not always applicable to printed circuit board manufacturing because the spray rinse may not reach many parts of the circuit board. However, spray rinsing can be performed along with immersion rinsing. This technique uses a spray rinse as the first rinse step after the workpieces are removed from the process tank. The spray rinsing typically takes place while the parts are draining above the process tank. This permits lower water flows in the rinse tank because spray rinsing removes much of the drag-out before the workpiece is submerged into the dip rinse tank.

Use fog nozzles. A variation on the spray nozzle is the fog nozzle. A fog nozzle employs water and air pressure to produce a fine mist. Much less water is needed than with a conventional spray nozzle. It is more often possible to use a fog nozzle rather than a spray nozzle directly over a heated plating bath to rinse the workpiece, because less water is added to the process bath using the fog nozzle.

Increase degree of agitation. Agitation between the workpiece and the rinse water can be performed either by moving the workpiece rack in the water or by creating turbulence in the rinse water. Since most printed circuit board manufacturing plants operate hand rack lines, operators could easily move workpieces manually by agitating the hand rack. However, the effectiveness of this system depends on cooperation from the operator.

Agitating the rinse tank by using forced air or water is the most efficient method for creating effective turbulence during rinse operations. This is achieved by pumping either air or water into the immersion rinse tank rinsing operations. Air agitation provides the best rinsing because the air bubbles create the best turbulence for removing the chemical process solution from the workpiece surface (USEPA 1982a). This type of agitation can be performed by pumping filtered air into the bottom of the tank through a pipe distributor (air sparger). Great care should be exercised, however, to ensure that the air is free of dust or oil so as not to contaminate the boards being cleaned. Assuming the plant has a sufficient quantity of compressed air onsite that is readily available, the cost of installing air spargers is $100 to $125 per tank for a 50 gallon capacity tank.

Use counter current rinse stages. Multiple stage rinse tanks increase contact time between the workpiece and the rinse solution and thereby improve rinsing efficiency compared to a single-stage rinse. If these multiple tanks are set up in series as a counter current rinse system, water usage can also be reduced. Manufacturers do not need to rely on large volumes of rinse water to prevent chemical concentrations in the rinse solution from becoming excessive. Multiple rinse tanks can be used to provide sufficient rinsing while significantly reducing the volume of rinse water used. A multistage counter current rinsing system can use up to 90 percent less rinse water than a conventional single-stage rinse system (Couture 1984).

The effectiveness of a multistage system in reducing rinse water usage is illustrated in the following example. A plant operates a process line where approximately 1.0 gallon of drag-out per hour results from a chemical process bath. This process bath is followed by a single-stage rinse tank. The process requires a dilution rate of 1000 to 1 to maintain acceptable rinsing in the tank. Therefore, the flow rate through the rinse tank is 1000 gal/hr. If a double stage counter current rinse system were used, a rinse water flow rate of only 30 to 35 gal/hr would be needed. If a triple stage counter current rinse system were used, only 8 to 12 gal/hr would be required (Watson 1973).

A multistage counter current rinse system allows greater contact time between the workpiece and the rinse water, greater diffusion of process chemicals into the rinse solution, and more rinse water to come into contact with the workpiece. The disadvantage of multistage counter current rinsing is that more process steps are required and additional equipment and work space are needed. A counter current triple-rinse system requires the installation of two additional rinse tanks and the associated piping. The cost of such a system is typically about $1,000 (Terran 1987).

Proper equipment design/operation. Printed circuit board manufacturers can use excessive amounts of rinse water if their water pipes are oversized or if the water is left on even when the rinse tanks are not being used. Rinse water control devices can be installed to increase the efficiency of a rinse water system. Flow restrictors limit the volume of rinse water flowing through a rinse system. These are used to maintain a constant flow of fresh water into the system once the optimal flow rate has been determined. Also, since most small and medium-sized printed circuit board manufacturers operate batch process lines in which rinse systems are manually turned on and off throughout the day, pressure activated flow control devices, such as foot pedal activated valves, can be helpful for assuring that the water is not left on after the rinse operation is completed. If the water lines are over-sized at a plant, pressure-reducing valves can be installed upgradient of the rinse water influent lines. This is also helpful for controlling water use in the rinse tanks.

A conductivity probe or pH meter can also be employed to control fresh water flow through a rinse system. A conductivity/pH cell is used to measure the level of dissolved solids or hydrogen ions in the rinse solution. When this level reaches a pre-set minimum, the conductivity probe activates a valve that shuts off the flow of fresh water into the rinse system. When the concentration builds to the pre-set maximum level, the probe again activates the valve, which then opens to continue the flow of fresh water. This control equipment is especially valuable to the printed circuit board manufacturing industry. A pH meter equipped with the necessary control valves and solenoids could cost approximately $700 per tank (Ryan 1987).

Use deionized water for rinsing. Natural contaminants found in water used for production processes can contribute to the volume of waste generated. During treatment of wastewater, these natural contaminants precipitate as carbonates and phosphates and contribute to the volume of sludge (USEPA 1982b). The extent to which these contaminants increase sludge volume depends on the hardness of the rinse water. In addition to the direct effect on sludge volume, the presence of natural contaminants in the water may reduce rinse water efficiency and the ability to reuse/recycle rinse water. Therefore, rinse systems may require more water than would be necessary if the water were pretreated.

The cost of deionizing process water depends on the condition of the water supplied to the plant. The cost is dependent on the concentration of total dissolved solids (TDS) in the water (Prothro 1987). For example, in the Santa Clara Valley a plant supplied with surface water spends approximately 2 cents per gallon to pretreat process water. A plant supplied with ground water spends close to 4 cents per gallon. A typical deionizing system that includes two 14-inch mixed bed deionizers costs approximately $2,000 for equipment and installation and treats up to 5,000 gallons a day (Prothro 1987).

RECOVERY/REUSE OF SPENT MATERIALS

Recycling and resource recovery includes technologies that use waste as raw material for another process or that recover valuable materials from a waste stream before the waste is disposed of. Opportunities for both the direct use of waste materials and the recovery of materials from a waste stream are available to the printed circuit board manufacturing industry. Many of the spent chemical process baths and much of the rinse water can be reused for other plant processes. Also, process chemicals can be recovered from rinse waters, and valuable metals such as copper can be recovered from waste streams.

A printed circuit board manufacturer must understand the chemical properties of its waste stream before it can assess the potential for reusing the waste raw material. Although the chemical properties of a process bath or rinse water solution may become unacceptable for their original use, these waste materials can still be employed in other applications. Printed circuit board manufacturers should therefore evaluate waste streams for properties that make them useful as well as properties that render them waste.

Segregate Streams to Promote Recycling

In a typical facility, the mixing of different rinse streams is not uncommon, and in the recent past, rinse waters and spent baths were frequently mixed and treated together. By segregating various rinses, their reuse or recycling can be promoted. Metal reclamation by electrolysis from various streams is made easier if they are not mixed.

Recover Metal Values from Bath Rinses

In the past, copper and other metal recovery from printed circuit board manufacturing has not proven to be economical. However, effluent pretreatment regulations have made the cost of treatment an economic factor. Also, the cost of management of sludges containing heavy metals has increased significantly because of the increased regulatory requirements placed on the handling and disposal of hazardous wastes. As a result, board manufacturers may now find it economical to recover copper and other metals and metal salts lost due to drag-out from process chemical baths.

Recovered metal can be used in two ways: (1) recovered metal salts can be recirculated back into process baths, and (2) recovered elemental metal can be sold to a metals reclaimer. Some of the technologies that are being successfully used to recover metals and metal salts include:

Evaporation. Waste rinse water is evaporated by heating, leaving behind a concentrated solution. The equipment used includes single or multiple effect evaporators. Vapor recompression applications have also been reported (Seaburg and Bacchetti 1982). In evaporative methods, the solution is concentrated until its metal concentration is equal to that of the plating bath, and then this solution is reused. Using this method, 90-99 percent efficient metal recoveries can be achieved (Clark 1984). Depending on the design, the evaporated water vapor can either be condensed and re-used as rinse water, or it can be vented off into the atmosphere (Campbell and Glenn 1982). Evaporation is the best established of all the metal recovery techniques used in electroplating. Although it is the most energy intensive recovery technique, its simplicity and reliability make it an attractive option for metal recovery. In order for evaporation to be economical, multiple counter current rinse tanks or spray/fog rinsing should be used to minimize the amount of rinse water being processed (MDEM 1984). Apart from the energy cost, a distinct disadvantage of evaporative techniques is that the concentrates may also contain the calcium and magnesium salts originally present in the rinse water. Adding them to the plating solution may result in its more rapid deterioration. This problem is alleviated in situations where rinse water is de-ionized or softened prior to use.

Reverse osmosis. Reverse osmosis is also used to recover drag-out that can be returned to the process bath. The reverse osmosis process employs a semipermeable membrane that permits only certain components to pass through. When pressure is applied, these components pass through the membrane and concentrate in the recovered solution. Although the technology is designed to recover drag-out, some materials (such as boric acid) can not be fully recovered and are, therefore, returned to the process bath at a lower concentration. Also, reverse osmosis is a delicate process that is limited by the ability of the membranes to withstand pH extremes and long-term pressure. Reverse osmosis systems are commonly used to recover nickel plating solutions and regenerate rinse waters.

Liquid membranes. Liquid membranes are composed of polymeric materials loaded with an ion-carrying solution (Basta 1983). Liquid membranes have been used to remove chromium from rinse waters and spent etching baths. Chromium in the form of dichromate is drawn across the membrane, forming a tertiary amine metal complex. This complex is then broken down on the other side of the membrane with sodium hydroxide solution.

Ion exchange. Ion exchange concentrates metals from a dilute rinse stream onto a resin material. As rinse water is passed through a bed containing the resin, the resin substitutes ions for inorganics in the rinse water. The metals are then recovered from the resin by cleaning it with an acid or alkaline solution. Ion exchange units can be used effectively on dilute waste streams and are less delicate than reverse osmosis systems. However, the equipment is complex and requires careful operating and maintenance practices.

Electrolytic recovery. This method recovers only the metallic content of rinse water. The process requires a cathode and an anode placed in the rinse solution. As current passes from the anode to the cathode, metallic ions deposit on the cathode. This type of system generates a solid metallic slab that can be reclaimed or used as an anode in an electroplating tank. Electrolytic systems can recover 90 to 95 percent of the available metals. Electrolytic recovery has been successfully used to recover gold, silver, tin, copper, zinc, solder alloy, and cadmium (Campbell and Glenn 1982). One great advantage of the electrolytic method over other metal recovery techniques is that it recovers only the plating metal, not the impurities, from the waste rinse water. Electrolytic metal recovery is most efficient on concentrated solutions. For solutions with less than 100 mg/l of the metal ion, low current efficiencies limit process effectiveness.

Electrodialysis. In electrodialysis, an electric current and selective membranes are used to separate the positive and negative ions from a solution into two streams. This is accomplished by feeding a solution through a series of alternating cation and anion selective membranes, through which a current is passed. Electrodialysis is used mainly to concentrate dilute solutions of salts or metal ions. Electrodialysis can remove nickel, copper, cyanide, chromium, iron and zinc from waste rinse water (MDEM 1984, Kohl and

Triplett 1984). This technology has not been used as widely in the electroplating industry as have other metal recovery techniques (Campbell and Glenn 1982, Kohl and Triplett 1984).

High surface area electrowinning/electrorefining. This method operates on the same principle as electrolytic recovery. The metal-containing solution is pumped through, and plates out on, a carbon fiber cathode (Mitchell 1984). To recover the metals, the carbon fiber cathode assembly is removed and placed in an electrorefiner, which reverses the current, removes the metals from the carbon fibers, and allows them to plate onto a stainless steel starter sheet. These systems can be used to recover a wide variety of metals and to regenerate many types of solutions.

The cost associated with implementing a chemical recovery technology depends on a number of variables: the size of the unit, the space available, equipment rearrangement, production down time, and the specific application. Table 3.3 contains cost data for several chemical recovery units from electroplating plants. Although the specific materials recovered may be different for a printed circuit board manufacturing plant, the basic technology is transferable between these two industries. While the equipment costs shown can be applied to board manufacturing, the annual savings depend on the wastewater metal concentrations and volume of wastewater treated by the recovery systems.

One limiting factor for a small printed circuit board manufacturing company is the volume and chemical concentration of its various rinse water effluents. The examples in Table 3.3 are all designed to recover a specific material from a single waste generating source (for example, nickel salts from a nickel plating line). To achieve savings in chemicals and sludge handling that create a justifiable payback, the waste stream must be fairly concentrated and continuous. Each company must evaluate its own conditions to determine the feasibility of material recovery. The information necessary to determine the feasibility includes waste stream generation rates and chemical concentrations, and the value of materials to be recovered.

TABLE 3.3

Costs of Technology for Material Recovery

Technology	Materials Recovered	Equipment Costs[a]
Evaporation Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$47,000
Reverse Osmosis Unit: Capacity of approximately 100 gph.	Nickel salt Plating chemicals	$27,000
Ion Exchange Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$38,000
Electrolytic Unit: Capacity of approximately 15 gph.	Rinse water Copper	$25,000

[a] Equipment costs include equipment purchase, installation, and materials.

Source: USEPA 1987.

Etching

Most of the source control techniques listed under plating and electroplating apply as well to waste produced by etching. Special source reduction methods associated with etching operations are discussed below.

Use differential plating instead of the conventional electroless plating process. If the concentrations of certain stabilizers in the electroless copper bath are controlled, copper deposits three to five times faster on the through-hole walls than on the copper cladded surface (Poskanzer and Davis 1982). This reduces the amount of copper that must be subsequently etched away in the subtractive method. The use of differential electroless plating has not been reported by printed circuit board manufacturers, and it may require significant developmental work before commercialization is possible.

Use non-chelated etchants. Non-chelate mild etchants such as sodium persulfate and hydrogen peroxide/sulfuric acid can be used to replace ammonium persulfate chelate etchant.

Use thinner copper foil to clad the laminated board. This change reduces the amount of copper which must be etched, and thus reduces the amount of waste generated from the etching process. Printed circuit board manufacturers are switching to boards cladded with thinner copper as their starting materials.

Use pattern instead of panel plating. Since panel plating consists of copper plating the entire board area, while pattern plating requires copper electroplating only the holes and circuitry, the use of the latter technique reduces the amount of non-circuit copper which must be subsequently etched away. This practice can therefore reduce the amount of waste generated from the etching operation. The switch from panel to pattern plating has been made by a large number of printed circuit board manufacturers. Customers demanding applications for a uniform cross section of circuitry in computer and microwave printed circuit boards, however, may dictate the use of panel plating to provide highly uniform copper thickness.

Use additive instead of subtractive method. This change eliminates the copper etching step, and therefore eliminates the generation of substantial volumes of spent etchant as well as reducing the amount of metal hydroxide sludges generated. Although the subtractive method is still the most widely used in the manufacturing of printed circuit boards, the additive method is gaining in popularity since it results in less waste and lower manufacturing costs (Brush 1983). A noted drawback to the additive method, however, is the requirement for solvent processable instead of aqueous processable photoresists. Furthermore, the spent additive plating bath often contains heavily complexed copper which may result in waste treatment problems.

Use non-chrome etchants. Whenever possible, ferric chloride or ammonium persulfate solution should be used instead of chromic-sulfuric acid etchants. Non-chromium etching solution has reportedly been used by printed circuit board manufacturers in an effort to reduce the toxicity of the waste generated.

Recycle spent etchants. Use of an electrolytic diaphragm cell for regenerating spent chromic acid from etching operations has been reported (AESI 1981). The electrolytic cell oxidizes trivalent chromium to hexavalent chromium and removes contaminants. The quality of the regenerated etchant has been reported to be equal to or better than fresh etchant.

In one such application, extensively tested at the U.S. Bureau of Mines in Rolla, Mo., copper etching solution was regenerated and metallic copper recovered at the same time. Recovery was accomplished by depositing the copper onto the cathode of the electrolytic diaphragm cell (Basta 1983).

Another recycling example involves the regeneration of cupric chloride, used as a strong etchant for producing circuit patterns on circuit board base material. The etchant becomes spent as the copper etched from the base material reduces the cupric chloride ($CuCl_2$) to cuprous chloride ($CuCl$). This spent etchant can be regenerated by oxidizing to cuprous chloride through direct chlorination (Couture 1984).

Wastewater Treatment

Process chemical loss due to drag-out is the most significant source of chemicals entering wastewater. Treatment of this wastewater is a major source of hazardous waste in PC board operation because of the resulting sludge. The volume of sludge generated is proportional to the level of contamination in the spent rinse water (Couture 1984). The major ways of reducing waste associated with treatment (in addition to those associated with drag-out reduction, reduction in the use of rinse water, and use of deionized water) include waste stream segregation, use of alternative treatment chemicals, and alternative treatment technologies.

WASTE STREAM SEGREGATION

Segregating waste streams can improve the efficiency of a waste treatment system. An example of waste stream segregation is the separation of chelating agent waste streams from nonchelating agent streams. Since most small printed circuit board manufacturing plants use treatment systems that can be operated as a batch process, they can implement waste stream segregation and selective treatment with minimal impact on the production system. The main drawback to this alternative is usually the limited storage capacity for the segregated waste streams.

If waste streams containing chelating agents are treated in a batch process separately from other waste streams, the use of ferrous sulfate to break down the chelators can be minimized. Since the iron in ferrous sulfate will precipitate out in the sludge, reduction in its use will also reduce the volume of sludge generated.

By isolating cyanide-containing waste streams from waste streams containing iron or complexing agents, the formation of cyanide complexes is avoided, and treatment made much easier (Dowd 1985). Segregation of wastewater streams containing different metals also allows for metals recovery or reuse. For example, by treating nickel-plating wastewater separately from other waste streams, a nickel hydroxide sludge is produced which can be reused to produce fresh nickel plating solutions.

Another waste alternative is to separate noncontact cooling water from industrial wastes. It is likely that this cooling water can bypass the treatment system and be discharged directly to the sewer because it does not come in contact with process chemicals. This practice can reduce wastewater volume and, as a result, reduce the amount of treatment chemicals used. Also, acidic or alkaline waste streams that do not contain metals can simply be neutralized prior to discharge; therefore, if they are segregated from other wastes that require metal removal, the volume of treatment chemicals can be reduced. This, in turn, will reduce the volume of sludge generated.

USE OF ALTERNATIVE WASTE TREATMENT CHEMICALS

The selection of chemicals used in the waste treatment process can affect the volume of sludge generated. This selection should, therefore, consider a chemical's effect on sludge generation rates. For example, lime and caustic soda are two common chemicals used for neutralization and precipitation. Although lime costs less per unit of neutralizing capacity, it can produce as much as ten times more dry weight of sludge than caustic soda (USEPA 1982b).

Alum and ferric chloride are commonly employed as coagulating agents to improve floc formation. When used, they convert to hydroxides and contribute to the volume of sludge. Polyelectrolyte conditioners can also be used as coagulants, but they are more expensive than inorganic coagulants. However, polyelectrolytes do not add to the quantity of sludge and may actually be less expensive overall when considering waste handling costs. One printed circuit board manufacturer visited during this study recently switched from alum to a polyelectrolyte coagulant in order to reduce sludge generation. Specific data on the volume of sludge reduction are not yet available from the company.

The selection of alternative treatment chemicals depends on specific waste characteristics and removal efficiency needs for a particular treatment facility. The potential use of various treatment chemicals should be discussed with chemical manufacturers' representatives and experimented with to determine their effectiveness.

ALTERNATIVE WASTEWATER TREATMENT - ION EXCHANGE

Ion exchange systems can be employed to treat the entire wastestream prior to discharge to the publicly-owned treatment works. When used for this purpose, the ion exchange units do not recover process chemicals for reuse because all sources of wastewater are mixed prior to treatment. The units can be used to recycle rinse water, however, by utilizing an activated carbon treatment system following ion exchange treatment. The costs for operating an ion exchange system depend on the volume and chemical concentrations of the wastewater.

One plant visited recently installed an ion exchange system to replace its conventional precipitation/clarification treatment system. The ion exchange unit is designed for a treatment capacity of 12 to 14 gallons per minute. The unit does not generate any sludge but does generate approximately two 55-gallon drums of spent ion exchange resin each month. The old treatment system generated approximately four to six 55-gallon drums of sludge per month.

The ion exchange system was purchased and installed for approximately $16,000 and required one week of production down time to install. The system costs $1,000 per month to operate, including material purchases and waste disposal, compared to $1,500 per month for the old system. The new system also requires less labor to maintain it. The payback on investment for the new system is estimated to be 3.3 years.

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Section Four

GUIDELINES FOR USING THE WASTE MINIMIZATION ASSESSMENT WORKSHEETS

Waste minimization assessments were conducted at several printed circuit board manufacturing plants in California. The assessments were used to develop the waste minimization questionnaire and worksheets that are provided in the following section.

A comprehensive waste minimization assessment includes a planning and organizational step, an assessment step that includes gathering background data and information, a feasibility study on specific waste minimization options, and an implementation phase.

Conducting Your Own Assessment

The worksheets provided in this section are intended to assist printed circuit board manufacturers in systematically evaluating waste generating processes and in identifying waste minimization opportunities. These worksheets include only the assessment phase of the procedure described in the *Waste Minimization Opportunity Assessment Manual.* For a full description of waste minimization assessment procedures, refer to the EPA Manual.

Table 4.1 lists the worksheets that are provided in this section.

Table 4.1 List of Waste Minimization Assessment Worksheets

Number	Title	Description
1.	Waste Sources	Typical wastes generated at printed circuit board manufacturing plants.
2A.	Waste Minimization: Material Handling	Questionnaire on general handling techniques for raw material handling.
2B.	Waste Minimization: Material Handling	Questionnaire on procedures used for bulk liquid handling.
2C.	Waste Minimization: Material Handling	Questionnaire on procedures used for handling drums, containers and packages.
3.	Option Generation: Material Handling	Waste minimization options for material handling operations.
4.	Waste Minimization: Material and Process Substitution	Questionnaire on material and process substitutions.
5.	Option Generation: Material and Process Substitution	Waste minimization options for material and process substitution.
6A.	Waste Minimization: Process Modification	Questionnaire extending process bath life by reducing drag-in and drag-out.
6B & 6C.	Waste Minimization: Process Modification	Questionnaire on: 1) extending bath life by avoiding decomposition and impurity removal; and 2) improving rinse efficiency.
7.	Option Generation: Process Modification	Process modification waste minimization options.
8.	Waste Minimization: Good Operating Practices	Questionnaire on use of good operating practices.
9.	Option Generation: Good Operating Practices	Waste minimization options for good operating practices.
10A.	Waste Minimization: Segregation, Reuse, Recovery and Treatment	Questionnaire on opportunities for segregation and reuse of wastes.
10B.	Waste Minimization: Segregation, Reuse, Recovery and Treatment	Questionnaire on opportunities for recovery and treatment of wastes.

Firm ____ Site ____ Date ____	Waste Minimization Assessment Proj. No. ____	Prepared By ____ Checked By ____ Sheet ___ of ___ Page ___ of ___

WORKSHEET
1

WASTE SOURCES

Waste Source: Material Handling	Significance at Plant		
	Low	Medium	High
Off-spec materials			
Obsolete raw materials			
Spills & leaks (liquids)			
Spills (powders)			
Empty container cleaning			
Container disposal (metal)			
Container disposal (paper)			
Pipeline/tank drainage			
Laboratory wastes			
Evaporative losses			
Contaminated wipes and gloves			
Other			
Waste Source: Process Operations			
Board Scrap			
Board Cleaners			
Catalysts			
Electroless Plating Baths			
Photoresist			
Developers			
Copper Plating Baths			
Tin/Lead Plate			
Stripping Solutions			
Etching Solutions			
Nickel/Gold Electroplate			
Reflow Oil			
Rinsing			
Equipment Cleaning			
Other			

Firm ______ Site ______ Date ______	**Waste Minimization Assessment** Proj. No. ______	Prepared By ______ Checked By ______ Sheet ___ of ___ Page ___ of ___

WORKSHEET
2A

WASTE MINIMIZATION: Material Handling

A. GENERAL HANDLING TECHNIQUES

Does the plant accept samples from chemical suppliers?	☐ yes	☐ no
Do unused samples become waste?	☐ yes	☐ no
Are suppliers required to take back unused samples they provide?	☐ yes	☐ no
Are all raw materials tested for quality before being accepted from suppliers?	☐ yes	☐ no

Describe safeguards to prevent the use of materials that may generate off-spec product: ______

Is obsolete raw material returned to the supplier?	☐ yes	☐ no
Is inventory used in first-in first-out order?	☐ yes	☐ no
Is the inventory system computerized?	☐ yes	☐ no
Does the current inventory control system adequately prevent waste generation?	☐ yes	☐ no

What information does the system track? ______

Is there a formal personnel training program on raw material handling, spill prevention, proper storage techniques, and waste handling procedures?	☐ yes	☐ no
Does the program include information on the safe handling of the types of drums, containers and packages received?	☐ yes	☐ no

How often is training given and by whom? ______

Describe spill containment used in material storage area: ______

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WORKSHEET
2B

WASTE MINIMIZATION: Material Handling

B. BULK LIQUIDS HANDLING

What safeguards are in place to prevent spills and avoid ground contamination during the filling of storage tanks?

High level shutdown/alarms ☐ Secondary containment ☐
Flow totalizers with cutoff ☐ Other ☐

Describe the system: ______

Are air emissions from solvent storage tanks controlled by means of:

Conservation vents	☐ yes	☐ no
Nitrogen blanketing	☐ yes	☐ no
Adsorber/Absorber/Condenser	☐ yes	☐ no
Other vapor loss control sytem	☐ yes	☐ no

Describe the system: ______

Are all storage tanks routinely monitored for leaks? ☐ yes ☐ no

Describe procedure and monitoring frequency for above-ground/vaulted tanks: ______

Underground tanks: ______

How are the liquids in these tanks dispensed to the users? (i.e., in small containers or hard piped.) ______

What measures are employed to prevent the spillage of liquids being dispensed? ______

When a spill of liquid occurs in the facility, what dry cleanup methods are employed (e.g., wet or dry)? Also discuss the way in which the resulting wastes are handled: ______

Would different cleaning methods allow for direct reuse or recycling of the waste? (explain): ______

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WORKSHEET
2C

WASTE MINIMIZATION: Material Handling

C. DRUMS, CONTAINERS, AND PACKAGES

Are drums, packages, and containers inspected for damage before being accepted? ☐ yes ☐ no
Are employees trained in ways to safely handle the types of drums & packages received? ☐ yes ☐ no
Are they properly trained in handling of spilled raw materials? ☐ yes ☐ no
Are stored items protected from damage, contamination, or exposure to rain, snow, sun & heat? ☐ yes ☐ no

Describe handling procedures for damaged items: ______

Does the layout of the facility result in heavy traffic through the raw material storage area? ☐ yes ☐ no
(Heavy traffic increases the potential for contaminating raw materials with dirt or dust and for causing spilled materials to become dispersed throughout the facility.)
Can traffic through the storage area be reduced? ☐ yes ☐ no

To reduce the generation of empty bags & packages, dust from from dry material handling and liquid waste due to cleaning of empty raw material drums, has the facility attempted to:

- Purchase hazardous materials in preweighed containers to avoid the need for weighing? ☐ yes ☐ no
- Use reuseable/recyclable drums with liners instead of paper bags? ☐ yes ☐ no
- Use larger containers or bulk delivery systems that can be returned to supplier for cleaning? ☐ yes ☐ no

Discuss the results of these attempts: ______

Are all empty bags, packages, and containers that contained hazardous materials segregated from those that contained non-hazardous wastes? ☐ yes ☐ no
Are containers properly "cleaned" (per EPA methods)prior to disposal? ☐ yes ☐ no

Describe the method currently used to dispose of this waste: ______

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WORKSHEET
3

OPTION GENERATION: Material Handling

Meeting Format (e.g., brainstorming, nominal group technique) ______

Meeting Coordinator ______

Meeting Participants ______

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. General Handling Techniques		
Quality Control Check		
Return Obsolete Material to Supplier		
Minimize Inventory		
Computerize Inventory		
Formal Training		
B. Bulk Liquids Handling		
High Level Shutdown/Alarm		
Flow Totalizers with Cutoff		
Secondary Containment		
Air Emission Control		
Leak Monitoring		
Spilled Material Reuse		
Cleanup Methods to Promote Recycling		
C. Drums, Containers, and Packages		
Raw Material Inspection		
Proper Storage/Handling		
Preweighed Containers		
Reusable Drums		
Bulk Delivery		
Waste Segregation		

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4

WASTE MINIMIZATION: Material and Process Substitution

To reduce the use of hazardous chemicals and the generation of hazardous wastes, has the facility attempted to use any of the following methods:

CLEANING AND SURFACE PREPARATION

Abrasives instead of solvents, acids, or alkalis?	☐ yes	☐ no
Non-chelated cleaning compounds?	☐ yes	☐ no

PATTERN PRINTING AND MASKING

Aqueous processable resist instead of solvent based resist?	☐ yes	☐ no
Screen printing instead of photolithography to eliminate need for developers?	☐ yes	☐ no
Dry photoresist removal methods to avoid use of organic strippers?	☐ yes	☐ no

ELECTROPLATING AND ELECTROLESS PLATING

Mechanical board production methods?	☐ yes	☐ no
Non-cyanide process baths?	☐ yes	☐ no
Non-cyanide stress relievers?	☐ yes	☐ no

ETCHING

Differential plating instead of conventional electroless plating?	☐ yes	☐ no
Pattern instead of panel plating?	☐ yes	☐ no
Additive instead of subtractive methods?	☐ yes	☐ no
Non-chelated etchants?	☐ yes	☐ no
Non-chromated etchants?	☐ yes	☐ no

WASTEWATER TREATMENT

Alternative (low dry solids volume) chemicals?	☐ yes	☐ no
Alternative treatment methods?	☐ yes	☐ no

Discuss the results of these attempts: ______________________________

____

____

Discuss the obstacles that prevent the use of these methods: ______________________________

____

____

Note: The auditor should refer to the USEPA report on Waste Minimization in Metal Parts Cleaning for information regarding material substitution and process modification aimed at reducing waste from parts cleaning.

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OPTION GENERATION: Material and Processing Substitution

Meeting Format (e.g., brainstorming, nominal group technique) ____

Meeting Coordinator ____

Meeting Participants ____

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Substitution Options		
Abrasives		
Non-chelated Cleaning Compounds		
Aqueous Processable Resist		
Screen Printing		
Dry Resist Removal		
Mechanical Production		
Non-cyanide Process Baths		
Non-cyanide Stress Relievers		
Differential Plating		
Use Thinner Copper Clading		
Pattern Plating		
Additive Method		
Non-chelated Etchants		
Non-chrome Etchants		
Other Raw Material Substitution		

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WORKSHEET
6A

WASTE MINIMIZATION: Process Modification

For cleaning, electroplating, electroless plating, and etching, there are many similar ways of reducing waste. This is because most of these operations involve the insertion and removal of a part from a tank of processing solution followed by the rinsing of the part in a tank of water. Waste can be reduced by extending process bath life (reduce drag-in, reduce drag-out, avoid bath decomposition and remove impurities) and by improving rinse efficiency.

A. EXTENDING PROCESS BATH LIFE

Drag-In Reduction

Are racks cleaned regularly to ensure that corrosion does not contaminate the process baths?	☐ yes	☐ no
Are coated racks used to avoid contamination?	☐ yes	☐ no
Has the plant investigated the use of purer anodes to avoid contamination from metallic impurities in the anodes?	☐ yes	☐ no
Are anode bags used to prevent corroded anodes from falling into the bath?	☐ yes	☐ no
Are anodes removed when the bath is not in use?	☐ yes	☐ no
Is rinsing adequate to prevent or minimize drag-in?	☐ yes	☐ no
Is deionized water used for process bath make-up?	☐ yes	☐ no
Are chemicals properly stored and mixed just before use to avoid decomposition and shortened bath life?	☐ yes	☐ no

Drag-Out Reduction

Are process baths operated at the lower end of the manufacturer's suggested range of operating concentrations?	☐ yes	☐ no
Are fresh process bath solutions operated at a lower concentration than replenished process bath solutions?	☐ yes	☐ no
Can any of the chemical process baths be operated at a higher temperature without adversely affecting production quality?	☐ yes	☐ no
Has the plant investigated the use of wetting agents to reduce drag-out?	☐ yes	☐ no
Are boards properly racked to avoid excessive drag-out (typical drag-out values should range from 10 to 15 ml/ft^2)?	☐ yes	☐ no
Are boards withdrawn slowly, and is ample time provided to allow for drainage?	☐ yes	☐ no
Has an optimal removal rate and drainage time for workpiece racks been determined for each process bath?	☐ yes	☐ no
Are personnel trained to follow proper workpiece rack removal rates & drainage times?		
Would use of an automatic board handler reduce drag-out?	☐ yes	☐ no
Is there space between process bath tanks and their associated rinse tanks that allows process chemicals to drip onto the floor?	☐ yes	☐ no
If yes, can drain boards be used to direct drainage back into the process tank?	☐ yes	☐ no
Do process baths that operate at elevated temperatures utilize drag-out tanks as the initial rinse following the bath?	☐ yes	☐ no
If yes, is the drag-out tank solution added back to the process tank?	☐ yes	☐ no
Has the company studied the possibility of using the drag-out solution for process bath replenishing?	☐ yes	☐ no

ırm ______ ;ite ______)ate ______	Waste Minimization Assessment Proj. No. ______	Prepared By ______ Checked By ______ Sheet ___ of ___ Page ___ of ___

WORKSHEET **6B**

WASTE MINIMIZATION: Process Modification

Avoiding Bath Decomposition and Impurity Removal

Is bath activity regularly monitored?	☐ yes	☐ no
Are corrective actions taken promptly to promote maximum bath life?	☐ yes	☐ no
Is bath temperature properly controlled?	☐ yes	☐ no
Are heating coils cleaned regularly?	☐ yes	☐ no
Has the plant used heated jacketed tanks instead of coils?	☐ yes	☐ no
Are the process baths agitated?	☐ yes	☐ no
Is agitation achieved by air sparging?	☐ yes	☐ no
Could mechanical agititation be used to avoid the formation of carbonates due to air agitation?	☐ yes	☐ no
Are process baths continuously filtered?	☐ yes	☐ no
Are they batch filtered?	☐ yes	☐ no
Is sludge build-up in the tank a problem?	☐ yes	☐ no
Would increased filtering help?	☐ yes	☐ no
Can coarser filters be used? (Coarser filters hold more sludge & need replacement less often.)	☐ yes	☐ no
Is carbon filtering employed?	☐ yes	☐ no
Has the plant attempted to regenerate/purify solutions by cooling or freezing?	☐ yes	☐ no
Can the recovered solids be used in another process? (Copper sulfate crystals from regenerated etchant may be used for regenerating copper electroplating baths.)	☐ yes	☐ no
Does the plant use an alkaline stripper to clean photoresist material off of printed circuit boards?	☐ yes	☐ no
Is the stripper decanted or filtered periodically to remove polymer flakes and increase the useful life of the stripper?	☐ yes	☐ no

B. IMPROVING RINSE EFFICIENCY

Can a still rinse or drag-out tank be employed to recover drag-out and reduce loading on the rinse system?	☐ yes	☐ no
If recovered drag-out cannot be returned to the process bath, is it treated separately from the spent rinse water?	☐ yes	☐ no
Does the plant use spray or fog rinsing to reduce rinse water use?	☐ yes	☐ no
Do all the rinse systems utilize forced air or forced water as a means of agitating the rinse solution?	☐ yes	☐ no
If no, are workpiece racks agitated manually while submersed in the rinse solution?	☐ yes	☐ no
Does the plant have the available space to install multiple counter-current rinse tanks at any of the rinsing stations?	☐ yes	☐ no
Have the flow rates used on all the rinse systems been determined based on rinsing needs of the particular process chemistry? (Based on a drag-out value of 15 ml/ft^2 and a required dilution ratio of 1000:1, a single stage rinse tank should use approximately 4 gallons of rinse per square foot of board.)	☐ yes	☐ no

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WASTE MINIMIZATION: Process Modification

B. IMPROVING RINSE EFFICIENCY (CONT.)

Does the sum of each rinse system's estimated daily water usage approximate the average daily volume of wastewater treated? (If no, rinse water lines are most likely being left on even when the process line is not in operation.)	☐ yes	☐ no
Does the plant utilize the flow restrictors, flow control meters, or other devices intended to regulate the flow of water through all the rinse tanks?	☐ yes	☐ no
Does the plant generate rinse water effluents from rinse operations that follow mild and/or strong acid etching and cleaning processes?	☐ yes	☐ no
If yes, are the rinse solutions recycled for use in rinse systems following alkaline cleaning baths?	☐ yes	☐ no
Has the plant investigated the use of deionized water for rinsing?	☐ yes	☐ no
Would the use of deionized rinse water promote the potential for recycling?	☐ yes	☐ no

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OPTION GENERATION: Process Modification

Meeting format (e.g., brainstorming, nominal group technique) ______

Meeting Coordinator ______

Meeting Participants ______

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
A. Extending Process Bath Life		
Proper Rack Design/Maintenance		
Purer Anodes and Anode Bags		
Better Rinsing		
Deionized Water		
Proper Storage		
Lower Bath Concentration		
Increase Bath Temperature		
Wetting Agents		
Proper Board Withdrawal/Drainage		
Automation		
Recover Drag-out		
Monitor Bath Activity		
Control Bath Activity		
Mechanical Agitation		
Filtering/Impurity Removal		
B. Improve Rinse Efficiency		
Still Rinses		
Spray Rinsing		
Fog Nozzles		
Increase Agitation		
Counter-current Rinse		
Proper Equipment Design/Operation		
Reuse/Recycle Rinse		
Use Deionized Water		

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8

WASTE MINIMIZATION: Good Operating Practices

Is the production schedule varied to decrease waste generation? (For example, do you attempt to increase size of production runs and minimize cleaning by accumulating orders or production for inventory?)

☐ yes ☐ no

Describe ____

Are plant material balances routinely performed?	☐ yes	☐ no
Are they performed for each material of concern (e.g. solvent) separately?	☐ yes	☐ no
Are records kept of individual wastes with their sources of origin and eventual disposal? (This can aid in pinpointing large waste streams and focus reuse efforts.)	☐ yes	☐ no
Are the operators provided with detailed operating manuals or instruction sets?	☐ yes	☐ no
Are all operator job functions well defined?	☐ yes	☐ no
Are regularly scheduled training programs offered to operators?	☐ yes	☐ no
Are there employee incentive programs related to waste minimization?	☐ yes	☐ no
Does the facility have an established waste minimization program in place?	☐ yes	☐ no
If yes, is a specific person assigned to oversee the success of the program?	☐ yes	☐ no

Discuss goals of the program and results: ____

☐ yes ☐ no

Has a waste minimization assessment been performed at the facility in the past?

If yes, discuss: ____

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OPTION GENERATION: Good Operating Practices

Meeting format (e.g., brainstorming, nominal group technique) ______

Meeting Coordinator ______

Meeting Participants ______

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
Increase Size of Production Run		
Perform Material Balances		
Keep Records of Waste Sources & Disposition		
Waste/Materials Documentation		
Provide Operating Manuals/Instructions		
Employee Training		
Increased Supervision		
Provide Employee Incentives		
Encourage Dry Cleanup		
Increase Plant Sanitation		
Establish Waste Minimization Policy		
Set Goals for Source Reduction		
Set Goals for Recycling		
Conduct Annual Assessments		

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WORKSHEET
10A

WASTE MINIMIZATION: Segregation, Reuse, Recovery, & Treatment

A. SEGREGATION

Segregation of wastes reduces the amount of unknown material in waste and improves prospects for reuse & recovery.

Are different solvent wastes segregated? ☐ yes ☐ no
Are aqueous wastes segregated from solvent wastes? ☐ yes ☐ no
Are spent solutions segregated from the rinse water streams? ☐ yes ☐ no

If no, explain: ____

Does the plant use chelators in any of the process baths? ☐ yes ☐ no
If yes, are waste streams that contain chelators segregated from other waste streams prior to treatment? (Waste streams that contain chelators often require additional treatment. This additional treatment will cause a greater volume of wastewater treatment sludge to be generated.) ☐ yes ☐ no

B. CONSOLIDATION/REUSE

Are many different solvents used for cleaning? ☐ yes ☐ no
If too many small-volume solvent waste streams are generated to justify on-site distillation, can the solvent used for cleaning be standardized? ☐ yes ☐ no
Is spent cleaning solvent reused? ☐ yes ☐ no
Does the plant generate spent alkaline and/or acidic baths that can be used for elementary neutralization in the industrial waste treatment process? ☐ yes ☐ no

Describe which measures were successful: ____

Has off-site reuse of wastes through Waste Exchange services been considered? ☐ yes ☐ no
Or reuse through commercial brokerage firms? ☐ yes ☐ no

If yes, results: ____

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10B

WASTE MINIMIZATION: Segregation, Reuse, Recovery, & Treatment

C. On-Site Recovery

On-site recovery of solvents by distillation is economically feasible for as little as 8 gallons of solvent waste per day.

Has on-site distillation of the spent solvent ever been attempted? ☐ yes ☐ no
If yes, is distillation still being performed? ☐ yes ☐ no

If no, explain: ______________________________
____
____

Does the plant generate waste streams that contain valuable process chemicals or metals? ☐ yes ☐ no
If yes, does the plant currently utilize any recycling technologies to recover valuable process chemicals or metals? ☐ yes ☐ no
Does the plant utilize treatment technologies to recycle rinse water? ☐ yes ☐ no
If no, has the plant assessed the potential for developing a closed loop rinse water system? ☐ yes ☐ no

Discuss the results of recycling: ______________________________
____
____

D. Alternative Treatment Technology

Does the plant operate an industrial waste treatment facility? ☐ yes ☐ no
If yes, does the treatment facility produce a wastewater treatment sludge that is handled as a hazardous waste? ☐ yes ☐ no
Has the plant evaluated the use of alternative treatment chemicals (such as caustic soda instead of lime or polyelectrolytes instead of alum or ferric chloride) to identify those that generate the lowest volume of sludge? ☐ yes ☐ no
If yes, has the plant evaluated the use of an alternative treatment system that produce less residual waste than the existing treatment facility? ☐ yes ☐ no

APPENDIX ONE

CASE STUDIES OF PRINTED CIRCUIT BOARD MANUFACTURING PLANTS

In 1986 the California Department of Health Services commissioned a waste minimization study (DHS 1987) of three printed circuit (PC) board manufacturing firms, called plants A, B and C in this guide. The results of the three waste assessments were used to prepare waste minimization assessment worksheets to be completed by other printed circuit board manufacturers in a self-audit process.

The three printed circuit board manufacturing plants were chosen for their willingness to participate in the study, their applicability to the study's objectives, and the potential usefulness of the resulting data to the industry as a whole. The waste minimization assessments were concerned with waste generated within the plant boundaries and not with waste derived from printed circuit board application or disposal of board parts.

This Appendix section presents the results of the assessments of Plants A, B and C and the waste minimization options either already in use or being considered for use by the firms.

The waste minimization assessments were conducted according to the description of such assessments found in the "Introduction: Overview of Waste Minimization," in this guide. The steps involved in the assessments were (see also Figure 1.1):

- Planning and organization
- Assessment phase
- Feasibility analysis phase

The fourth phase, Implementation, was not a part of these assessments since they were conducted by an outside consulting firm. It was left to the printed circuit board manufacturers themselves to take steps to implement the waste minimization options that passed the feasibility analysis.

PLANT A WASTE MINIMIZATION ASSESSMENT

Planning and Organization

Planning and organization of the assessment was done by the consulting firm with the assistance of personnel from the PC board manufacturing firm. Initial contact was made with the PC board manufacturer's plant operations manager, a high level manager who could provide the company's commitment to cooperate in the assessment and provide all the necessary facility and process information. The goal of this joint effort was to conduct a comprehensive waste minimization assessment for the plant. Under different circumstances, in a company with its own on-going waste minimization program, goals could be set to target a specific amount or type of waste to be reduced; or to conduct a waste minimization assessment each year; or other goal. The waste assessment task force in the case of Plant A consisted of the consultants working together with the plant manager. This task force also functioned as the assessment team.

Assessment Phase: Process and Facility Data

Initial discussions by telephone between the consultants and the plant manager were used to request process and facility information prior to a site visit. These discussions also served to identify particular waste streams of concern to plant managers.

At the site visit, the plant operations manager and consultants met to review the facility's operations and its potential target waste streams. The manager conducted a facility tour and introduced the consultants to process managers and workers involved in materials and waste handling. Some of these people were interviewed to obtain information about specific procedures used at the plant.

FACILITY DESCRIPTION

Plant A is a prototype circuit board manufacturer that specializes in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), photoresist printing, plating, etching, and stripping.

PROCESS DESCRIPTION

Figure A1 is a floor plan of the plant's plating, etching, and stripping operations. The numbers listed on the floor plan represent the identification number for each process bath and rinse tank. Tables A1, A2, and A3 provide information on the plant's operations. Table A1 describes each process bath used at plant A and Table A2 describes each rinse system used at the plant.

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating, etching, and stripping processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, industrial waste treatment, and equipment cleanout. Table A3 describes the hazardous wastes produced at the plant.

Spent Chemical Bath

When a process chemical bath becomes too contaminated or diluted for use (spent), it is removed from the process tank. The spent chemical bath is then either containerized for reclaim by the manufacturer, containerized for off-site disposal, used as a neutralization chemical in the industrial waste treatment system, or dumped into the wastewater collection sump. The chemical baths are changed periodically according to the plant's current time schedule. This schedule was developed by Plant A based on its experience with various process baths.

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods are containerizing waste for off-site disposal and dumping of spent chemical baths into the wastewater sump. Two process chemical baths are containerized for disposal: (1) photoresist stripper and (2) reflow oil. Approximately 55 gallons of waste stripper are generated monthly. Plant A did not estimate the volume of waste reflow oil generated each month.

Photoresist stripper waste is generated at the conditioning and stripping line. The stripper is used in a 30-gallon tank where circuit boards are immersed to strip off the remaining photoresist material. The chemical bath is changed approximately every 2 weeks. The resultant stripper waste is highly alkaline with a pH over 12. The waste stripper contains a polymer residue which, when agitated, remains suspended in the solution.

Reflow oil is used to enhance the formation of a smooth, uniform film of solder onto printed circuit boards. The reflow oil bath is maintained at an elevated temperature during use. When the bath becomes spent, it is containerized for off-site disposal. Analytical data for the spent oil were not available.

The plant's standard practice for dumping spent chemical baths into the wastewater sump is to transfer waste chemicals to one of the two metering tanks (tanks A and B in Figure A1). These tanks slowly discharge waste chemicals into the waste sump. The purpose for slowly feeding the spent bath chemicals into the wastewater sump is to prevent surges in the waste stream pH or metals content. These two metering tanks have not, however, been

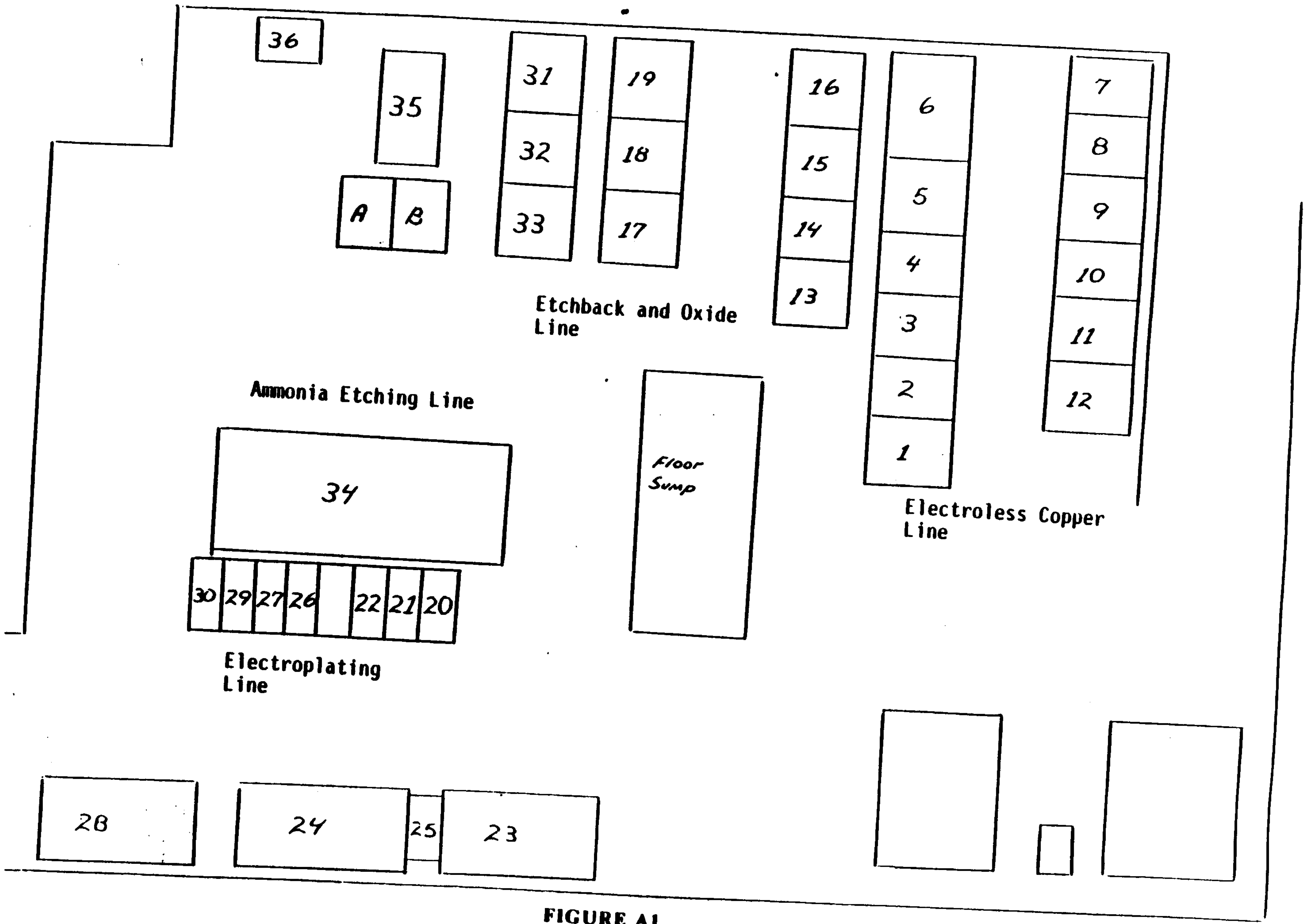


FIGURE A1
PLANT A'S PLATING
ETCHING AND STRIPPING OPERATIONS

TABLE A1
PROCESS BATH INFORMATION

PROCESS BATH/ IDENTIFICATION NUMBER	PROCESS BATH VOLUME (gallons)	METHOD OF DISPOSAL IN TANK	FREQUENCY OF DUMPS
Cleaner-Conditioner/1	30	To treatment	2 weeks
Sulfuric-Peroxide Etch/3	30	To treatment	4 weeks
Catalyst Premix/5	30	To treatment	2 weeks
Catalyst/6	30	---	---
Accelerator/8	30	To treatment	2 weeks
Electroless Copper/11	30	---	---
5% Sulfuric Acid/12	30	To treatment	2 weeks
100% Sulfuric Acid/13	30	To treatment	1 week
Neutralizer Etchback/15	30	To treatment	4 weeks
Brown Oxide/17	30	---	---
Ammonium Biflouride/19	30	To treatment	4 weeks
Metex Cleaner/20	20	To treatment	1 week
10% Sulfuric Acid/22	400	To treatment	1 week
Copper Gleam/23	400	---	3 years
Copper Gleam/24	400	---	3 years
10% Fluorboric Acid/27	20	To treatment	2 weeks
Tin Lead/28	400	---	3 years
Resist Stripper/31	30	Off-site disposal	2 weeks
Tin Immersion Conditioner/33	30	Reclaimed by supplier	---
Ammoniated Etch/34	---	Reclaimed by supplier	4 weeks
Reflow Oil/36	30	Off-site disposal	---

TABLE A2
RINSE SYSTEM INFORMATION

RINSE SYSTEM/ NUMBER	RINSE WATER FLOW RATE	NUMBER OF TANKS	COUNTER CURRENT SYSTEM (Y/N)	PROCESS BATH(S) PRECEDING RINSE SYSTEM	ESTIMATED DAILY WATER USE
Dip Rinse/12	16 gal/min	one	no	Cleaner/ conditioner	1500 gallons
Dip Rinse/4	16 gal/min	one	no	Sulfuric/ peroxide etch	1500 gallons
Dip Rinse/7	16 gal/min	one	no	Catalyst	1500 gallons
Dip Rinse/9	16 gal/min	one	no	Accelerator	1500 gallons
Dip Rinse/10	16 gal/min	two	no	Rinse tank #9	1500 gallons
Dip Rinse/14	16 gal/min	one	no	Sulfuric acid	500 gallons
Dip Rinse/16	16 gal/min	one	no	Neutralizer etchback	500 gallons
Spray Rinse/21	1.5 gal/min	one	no	Metex cleaner	---
Drag-out/25	---	one	no	Gapper gleam	---
Spray Rinse/26	1.5 gal/min	one	no	Sulfuric acid	---
Drag-out/29	---	one	no	Fluorboric acid	---
Spray Rinse/30	1.5 gal/min	one	no	Drag-out tank #29	---

TABLE A3
HAZARDOUS WASTE DATA

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Industrial Waste Treatment Sludge	2,400 gal.	off-site metal reclamation	$1.00/gal	$2,400
Photoresist Stripper	720 gal.	off-site disposal	---	---
Reflow Oil	---	off-site disposal	---	---
Nitric Acid	120 gal.	off-site disposal	---	---
Copper Sulfate Crystals	---	off-site disposal	---	---

in operation since July 1986. The present practice is to manually dump the spent baths into the collection sump. Plant A personnel indicated that this practice causes a fluctuation in the pH of the waste stream entering the treatment system.

Copper sulfate crystals are generated when some of the process baths are taken off-line. The crystals form in the process bath as the copper content increases. Before the process baths are dumped into the wastewater sump, the crystals are removed and containerized as a solid waste since they cannot be fed into the treatment system.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant A. Plant A estimates that approximately 10,000 gallons of wastewater are generated each day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge that is generated from this treatment is handled as a hazardous waste.

Plant A uses nine dip rinse tanks and three spray rinse tanks. All rinse water used at Plant A is deionized onsite prior to use. All but two of the rinse tanks are plumbed directly to the wastewater treatment system through a 500-gallon collection sump. The other two are batch dump tanks which require manual dumping into the sump.

Discussions with facility personnel indicate that water flows through the dip rinse tanks only when the process line associated with the tank is in operation. However, during both visits, the assessment team observed water flowing through several rinse tanks even when the process line was not being operated. The flow rate of water through each dip rinse tank was measured to be approximately 16 gallons per minute. This was measured by closing the drain line, turning on the feed water for 20 seconds, measuring the water level rise in the rinse tank, and calculating the volume of water that entered the tank during the time period. The flow rate of water through the spray rinse tank has been estimated by the assessment team to be approximately 1.5 gallons per minute.

Industrial Wastewater Treatment

Plant A's industrial waste treatment facility treats all wastewater before discharging it to the San Jose/Santa Clara Water Pollution Control Plant. Plant A's treatment facility removes metals and adjusts the pH of the wastewater to meet discharge requirements set by the water pollution control plant. The maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/Santa Clara Water Pollution Control plant, are as follows:

- Chromium 1.0 mg/L
- Copper 2.7 mg/L
- Cyanide 1.0 mg/L
- Lead 0.4 mg/L
- Nickel 2.6 mg/L
- Silver 0.7 mg/L
- Zinc 2.6 mg/L

The treatment process includes metal reduction, neutralization, and flocculation. The treatment plant is located outside the main building in a fenced and curbed area. The metal hydroxide sludge generated by the treatment process is a hazardous waste.

Chemical treatment is performed in three separate tanks; the wastewater then goes through sludge separation and dewatering. Approximately 10,000 gallons of wastewater are treated each day. Wastewater characterization data were not provided by Plant A. The incoming wastewater is pumped from the collection sump to the first tank where ferrous sulfate and sulfuric acid are added. Ferrous sulfate is used to reduce the copper to its precipitable form. The sulfuric acid is used to maintain the pH between 2.0 and 3.0 during the ferrous sulfate reaction. The waste is then neutralized with alum and sodium hydroxide. The alum causes the suspended solids to collect, forming larger particles, and the sodium hydroxide raises the pH to approximately 9.0. A polyelectrolyte coagulant is then introduced to aid in the flocculation of the contaminants. The polyelectrolyte causes the precipitated contaminants to congeal into large flakes which can be settled out of the waste stream. Plant A personnel provided information on the quantities and costs of treatment chemicals used each month (Table A4).

TABLE A4

QUANTITIES AND COSTS OF TREATMENT CHEMICALS - PLANT A

Chemical	Monthly Usage	Cost/Unit	Cost/Month
Ferrous sulfate	850 lbs	$0.33/lb	$280
Alum	850 lbs	$0.47/lb	$400
Sodium hydroxide	200 gallons (30% solution in winter)	$0.55/gal	$110 winter
	(50% solution in summer)	$0.92/gal	$185 summer
Polyelectrolyte	3 lbs	$7.50/lb	$ 22
		Total	$812/in winter
			$887/in summer

The wastewater treatment sludge that is settled out of the effluent waste stream is transferred to the sludge dewatering unit, and the effluent is discharged to the San Jose/Santa Clara Water Pollution Control Plant. Sludge is dewatered in a bag filter that increases its solids content to 11 percent. The dewatered sludge is transferred into 55-gallon drums and stored for pickup by a metal reclaimer (World Resources Company). Plant A plans to use large storage bags in the future which will hold the equivalent of four 55-gallon drums. Plant A estimates that four drums of industrial waste sludge are generated each month. The sludge is considered a hazardous waste because of the copper content.

Analytical data for the sludge were obtained from World Resources Company of Phoenix, Arizona. World Resources analyzes a sample from each load of sludge transported to them for metal reclamation. The data provided by World Resources are as follows:

Percent solids 11%

Metal content in pounds per dry ton

Copper	195
Nickel	6
Tin	46
Iron	399
Zinc	9
Lead	23
Chromium	20

Equipment Cleanout

The primary sources of hazardous waste associated with equipment cleanout are the cleaning of the copper etching tank, cleaning of tanks used in the electroplating line, and cleaning of electroplating racks. This equipment is cleaned by using nitric acid. Plant A estimates that one 55-gallon drum of waste nitric acid is generated every 6 months. The waste nitric acid has too low a pH and too high a copper content to be treated at the plant's wastewater treatment system. Analytical data on the waste nitric acid were not available from Plant A.

Other cleaning activities, such as floor washing and chemical bath tank rinsing, generate waste streams that discharge into the wastewater collection sump. According to Plant A personnel, these waste streams make up a small portion of the chemicals that enter the treatment system.

Assessment Phase: Option Generation

The consultants reviewed the plant operations data obtained prior to and during the site inspection. They developed a set of waste minimization options based on this information and on information in the literature. These options were screened for their effectiveness in reducing waste and for their future implementation potential. The plant manager participated in this screening, with the result that there was general consensus on the list of recommended options.

SOURCE REDUCTION

The following paragraphs describe the application and use of source reduction measures to various waste streams at Plant A.

Material Substitution

Opportunities for material substitution that apply to Plant A include (1) using process chemistries that can be recycled or treated prior to discharge to the publicly owned treatment works (POTW) and (2) using chemistries that have less impact on sludge generation. Process chemistries that Plant A currently containerizes for off-site disposal include spent reflow oil and nitric acid waste. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the POTW. Plant A could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from the cleaning of electroplating racks, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks can be plated out in a tank equipped with a cathode and an anode. The metallic sludge then settles to the bottom of the cleaning tank where it can be removed and mixed with the wastewater treatment sludge. Once the cleaning solution becomes spent, it can be treated in the plant's industrial waste treatment system before being discharged to the POTW. The use of recyclable cleaning solution will eliminate the generation of waste nitric acid. The metallic sludge that is generated can be sent to a metal reclaimer along with the wastewater treatment sludge.

The use of non-chelated process chemistries can reduce the volume of sludge generated during wastewater treatment. Plant A uses ferrous sulfate to treat its wastewater. The ferrous sulfate is used to break down chelators so that metals can be precipitated. The iron in ferrous sulfate also precipitates as a metal hydroxide and contributes to sludge volume. The analytical data for Plant A's industrial waste treatment sludge indicate that iron contributes approximately 57 percent of the total metal content of the sludge. If all the iron precipitates as metal hydroxide, the iron hydroxide contributes 34 percent of the total dry weight of the sludge. If plant A used non-chelated process chemistries, ferrous sulfate treatment could be eliminated and sludge generation could be reduced. Most chemical suppliers offer non-chelated process chemistries or chemistries with mild chelators that do not require ferrous sulfate treatment. Plant A should consult with chemical suppliers to identify alternative process chemistries that can be used so that ferrous sulfate treatment can be minimized.

Rinse Water Reduction

Although rinse water is not a hazardous waste, the treatment of this waste produces a sludge that is a hazardous waste. Since the volume of the sludge generated by treatment is a function of the volume of wastewater treated as well as the concentration of contaminants in the waste, the plant can reduce the volume of sludge generated by reducing its rinse water generation. Several rinse reduction options are available to Plant A that can reduce the volume of wastewater requiring treatment. Multiple stage rinse water systems were not evaluated because not enough space is available at Plant A's facility.

Rinse Tank Operations

Plant A now operates several of its dip rinse tanks as flow-through tanks. Deionized water is plumbed into the tank during operation and the overflow is plumbed to the collection sump. Each of the rinse tanks holds approximately 30 gallons of rinse water, and the flow of water through each tank is approximately 16 gallons per minute. PRC believes that the plant could modify its operation of these rinse tanks to reduce the volume of wastewater generated. Two options are available for Plant A: (1) the dip rinse tanks can be operated as batch rinse tanks or (2) the flow rate through the tanks can be reduced.

If these seven dip rinse tanks were operated as batch rinse tanks (which means they would operate as stagnant rinse tanks that are emptied between rinse operations and then refilled with deionized water), Plant A could reduce its rinse water generation significantly. Table A4 shows the volume of rinse water generated by Plant A and the volume that would be generated if the seven dip rinse tanks were operated as batch rinse tanks. The values for the time water is running and for the number of workpiece racks processed daily were provided by Plant A personnel. This option assumes that each rinse tank can provide adequate rinsing of one process rack when filled with fresh deionized water. Plant A did not provide the auditors with information on the required operating parameters of the rinse systems. Therefore, the impact of batch rinsing on the efficiency of the rinsing operations could not be assessed. The following example, however, illustrates the feasibility of batch rinsing.

The equation for determining the volume of rinse water needed to rinse a full workpiece rack is as follows:

$$Q = D(C_p/C_n)$$

Where Q = rinse tank flow rate

D = drag-out rate

C_p = concentration of salts in process solution

C_n = allowable concentration in rinse solution

Several assumptions must be made to use this equation to illustrate the potential for operating the rinse tanks as a batch rinse system. These are as follows:

- o The concentration of chemicals in the rinse solution cannot exceed 1/1000 of the concentration of chemicals in the process bath. This value is a common parameter used in the electroplating industry for rinse water contaminant concentration.

- o The drag-out rate of chemicals used for manufacturing printed circuit boards is approximately 15 ml/ft^2 of board. This value is a standard approximation used for estimating drag-out created by a printed circuit board (Foggia, 1987).

- o An average workpiece rack holds approximately 2.5 ft^3 of boards (example: 30 4-inch by 3-inch boards).

The drag-out rate for each workpiece rack is:

$$15 \text{ ml} \times 2.5 \text{ ft}^3 = 37.5 \text{ ml.}$$

Converted to gallons, drag-out equals 0.01 gallon.

By substituting the values into the equation:

$$0.01 \text{ gallon} \times \frac{1000}{1} = 10 \text{ gallons}$$

10 gallons of fresh rinse water will provide adequate rinsing under the operating parameters previously described. Since the rinse tanks hold approximately 30 gallons of rinse water, theoretically, a full tank of fresh water would provide adequate rinsing without operating the tank as a flow-through tank. Workpiece rack agitation or air spargers can be used to improve efficiency to assure adequate rinsing in the batch rinse tank.

Although using the dip rinse tanks as a batch process can provide significant reductions in wastewater generation, there may be several process lines for which this is not feasible because of the chemistry of the process. However, even if some of the tanks must operate as flow-through rinse systems, the volume of deionized water used can still be reduced for these tanks. The same equation can be used to demonstrate that the present flow rate used in the rinse tanks may be excessive.

The equation can be rearranged to indicate the ratio of process bath concentration to rinse solution concentration, as follows:

$$\frac{Q}{D} = C_p/C_n$$

The same drag-out volume (0.01 gallon) will be used, and it will be assumed that the process rack remains in the rinse tank for 3 minutes. The ratio of the process bath concentration to rinse solution concentration is as follows:

$$\frac{16 \text{ gals/min} \times 3 \text{ min}}{0.01 \text{ gal.}} = 4{,}800$$

Therefore, to justify the present rinse water flow rate, the concentration of chemicals in the rinse solution can only reach 1/4,800 or 2/10,000 of the concentration of chemicals in the process bath before rinse efficiency is reduced. As previously stated, the electroplating industry usually allows rinse water concentrations to reach 1/1000 the concentration of chemicals in the process tank. Plant A should consult chemical manufacturers' representatives and perform experiments to determine the proper flow rate for its rinse tanks if batch operation is not feasible.

By calculating the flow rate necessary to maintain the rinse water at an acceptable chemical concentration , Plant A may find that the 16 gallon per minute flow rate presently used is too high. In addition, the use of air spargers or work piece rack agitation should improve rinse efficiency and allow for use of lower rinse water flow rates.

Rinse Water Flow Controls

Plant A presently turns on the rinse water in-flow valves manually. When the process line is in operation, plant personnel turn on the water for all the rinse tanks and then turn the water off after the production process is complete. However, the consultants observed that rinse tanks were left on even when the process line was not in use. The use of automated flow controls would be helpful for ensuring that rinse water is not left running and for controlling the flow rate when the rinse water is turned on.

The plant should consider installing pH meters in each of the rinse tanks to control the flow of water through the rinse systems. The meters should be set to turn the fresh water feed valve on when the chemical concentration in the rinse gets too high. If the required pH range for each rinse tank is determined, the meters can be set to turn on the water automatically. When the rinse tank solution pH reaches the maximum allowable level to provide efficient rinsing, the meter will send a signal that activates a valve on the influent line. When the rinse solution again reaches an acceptable pH, the pH meter will send a signal that turns off the water feed valve.

Flow restrictors can also be used to reduce flow rates. A limiting orifice or similar flow-restricting device can be installed in the water line to each tank to reduce the flow rate to each tank. Plant A uses approximately 2-inch diameter piping for its rinse inflow lines. This piping may be oversized for the pressure on the line and the required flow rate. The use of flow restrictors, therefore, may provide better controls over the rate of rinse water usage. One circuit board manufacturer who installed pH meters, flow restrictors, and other water reduction devices, such as foot pedal pressure switches, was able to reduce water usage by two thirds.

Process Bath Drag-Out

Process bath chemicals are carried into the rinse water when the racks that hold the printed circuit boards are removed from a process bath tank and placed in a dip rinse tank. This is performed manually at Plant A. The operator removes the rack, briefly holds it above the process bath tank, and submerges the rack into the rinse tank. The consultants personnel observed plant personnel performing this operation and found that the racks are quickly removed from the process bath and held over the process bath tanks for less than 10 seconds. This procedure allows excessive chemicals to enter the waste rinse water stream. Actual drag-out volumes were not available from Plant A, however.

The manner in which racks are removed from process baths will significantly affect the amount of drag-out carried into the rinse tanks. Slow removal of workpieces causes a much thinner film of process chemicals to adhere to the workpiece surface. This effect is so significant that most of the workpiece drainage time should be used to remove the workpiece rack from the process bath. The consultants observed that Plant A personnel remove racks in one quick movement. We suggest that Plant A train its personnel to remove racks in a slow, smooth manner. Plant A could also improve the drag-out recovery efficiency of the process lines by installing a bar or rail above the process tank so that the racks can be hung and allowed to drain longer.

The auditors did not predict the drag-out volume that can be recovered by removing racks at a slower rate and allowing racks to drain for a longer period of time. However, the savings realized by reducing drag-out losses include reducing process chemical purchases and reducing wastewater treatment sludge generation. Plant A can determine the effectiveness of these drag-out reduction techniques by holding the racks over a collection pan after removing them. The volume of drag-out that can be recovered after removing racks at various rates and allowing racks to drain for various lengths of time can then be measured and the optimal removal rate and drainage time can be determined.

Equipment Cleanout

Plant A generates approximately 55 gallons of waste nitric acid every 6 months from cleaning out the electroplating tanks and from cleaning the electroplating racks. Plant A may be able to reduce the volume of nitric acid generated by modifying the existing cleaning methods.

One method for reducing the volume of waste nitric acid produced is to set up a workpiece rack cleaning line with several small tanks of nitric acid. The cleaning line is then used like a multi-stage rinse system. The first tank contains the most contaminated nitric acid solution and the final tank in the cleaning line contains the freshest nitric acid. When the first tank no longer performs adequate initial cleaning, it is containerized for disposal (or used as initial cleaning solution for tank cleanout). Then the second tank in the cleaning line becomes the first. The empty tank is then filled with fresh nitric acid and it becomes the last tank in the cleaning line.

The use of a multi-stage rinse system can provide significant reductions in waste cleaning solution generation. One printed circuit board manufacturing plant visited by the consultants uses a five-stage multiple tank cleaning line and only generates approximately 15 gallons of waste nitric acid each 6 months.

Chemical Process Baths

The chemical load on wastewater can be reduced by operating the process baths at lower concentrations. A manufacturer's recommendations for chemical concentrations in process baths are not always appropriate. We recommend that Plant A evaluate the efficiency of the concentration parameters of its present chemical process bath to determine if these concentrations can be reduced. By reducing the concentration of chemicals in a process bath, the plant will minimize the chemical load in the wastewater when these baths are dumped. This reduction will also reduce the chemical concentration in the rinse water by minimizing drag-out chemical loses.

One method of reducing process bath chemical concentrations is to operate fresh baths at lower concentrations than older baths. Plant A can accomplish this by gradually increasing the chemical concentration in the process bath as it gets older. This practice can reduce the chemical concentration of the drag-out from fresh baths and also extend the life of some process baths.

Waste Segregation

The wastewater generated at Plant A is plumbed or manually dumped into a 500-gallon collection sump. Therefore, all wastes that can be treated on-site are mixed prior to treatment. This practice may cause excessive use of treatment chemicals and an increase in the volume of sludge generated. Waste segregation may reduce the use of treatment chemicals and the generation of sludge in two areas: the non-contact cooling water used for the copper etch machine and the waste streams generated by processes that contain chelating chemistries.

Plant A personnel indicated that the cooling water system used in the copper etcher is a once-through system, with the effluent discharged to the collection sump. If the system were operated as a closed loop system, there would not be an effluent waste stream. Also, since this water is used as non-contact cooling water, the effluent that is now generated by the system may not require treatment. The effluent, therefore, could possibly be discharged directly to the sanitary sewer, if permitted by the Publicly-Owned Treatment Works (POTW).

The use of a closed loop cooling system would lead to reductions in water and sewer fees, treatment chemical use, and sludge generation. Direct discharge of non-contact cooling water to the sanitary sewer would result in savings from reduced treatment chemical use and sludge handling. The consultant was unable to obtain estimates on the volume of water used in the etcher cooling system; therefore, specific values for savings cannot be presented.

The primary purpose of the treatment system used at Plant A is to remove metals from the waste stream so that the discharged effluent can meet San Jose/Santa Clara Water Pollution Control Plant pretreatment standards. The highest metals concentration in the wastewater is copper, and the treatment system is designed to remove the copper through a ferrous sulfate reduction process. The ferrous sulfate process is designed to break down chelators that keep metals in solution past their normal solubility limit. The ferrous sulfate contributes significantly to the volume of sludge generated in the wastewater treatment process. Analytical data indicate that iron content in the sludge is 399 pounds per dry ton of solids. Assuming that all the iron precipitates as a hydroxide, iron hydroxide contributes 34 percent of the total dry weight of solids in the sludge. If there is a direct relationship between solids content and total sludge volume, the plant could reduce sludge volume by 34 percent by eliminating iron from the waste treatment system.

Several options are available to eliminate or reduce the amount of ferrous sulfate used in the treatment process. These include: (1) eliminating the use of chelated process chemistries, (2) using process chemistries that only contain mild chelators, (3) segregating waste streams that contain chelators from other waste streams, and (4) segregating waste streams that contain copper from other waste streams. Plant A was unable to identify which process baths use chelators or what type of chelators are used. Therefore, specific recommendations for waste segregation cannot be developed. However, several waste segregation options are described.

Use of non-chelated process chemistries or mild chelators may allow Plant A to eliminate the use of ferrous sulfate. Since the primary purpose of ferrous sulfate is to break down chelators so that copper can be precipitated from the wastewater, non-chelated process chemistries would allow the use of an alternative precipitant such as caustic soda. Mild chelators, such as ethylenediamine tetraacetic acid (EDTA), can be broken down through pH reduction. Therefore, if EDTA is used where chelators are needed, such as in an electroless copper bath, ferrous sulfate may not be required for wastewater treatment.

Mixing waste streams that contain chelating agents with waste streams that are non-chelated appears to cause a significant increase in the amount of treatment chemicals used, and should be avoided when possible. Ferrous sulfate use can also be reduced by segregating waste streams. According to Plant A personnel, the sources of copper that enter the wastewater are (1) the copper drag-out tank, (2) spray rinse tank 29, and (3) dip rinse tanks 9 and 10. If these waste streams were segregated from the rest of the wastewater, ferrous sulfate treatment would only be necessary for a percentage of the waste. This could be done on a batch treatment basis if a holding tank is used to store the waste until treatment. The remaining wastewater could have metals removed by neutralization and precipitation with caustic soda. This would reduce the amount of treatment chemicals used at the facility. If other waste streams contain chelators, these could also be segregated from the rest of the waste stream.

RECYCLE AND RESOURCE RECOVERY ALTERNATIVES

Recycling and resource recovery includes the direct use of a waste stream or the recovery of materials from a waste stream. Plant A appears to handle many of its waste streams in this manner. Spent sulfuric acid is used in the wastewater treatment system, and several chemical process baths are returned to the manufacturer when they become spent. This chapter describes several additional recycling and resource recovery techniques that may be implemented by Plant A.

Stripper Waste

Plant A personnel indicated that the plant's stripper waste is an alkaline solution that could be reused or used in the treatment system if the polymer residue could be removed. The plant could use a filter or decantation system to separate the residue from the waste solution. Also, the volume of stripper waste generated can be reduced significantly by using a multiple tank stripper system. This type of system allows the first stripper tank (the one with the most contaminated stripper solution) to be used for a longer period of time because the second stripper tank will be used for additional photoresist stripping. Therefore, the photoresist stripper does not have to be replaced every 2 weeks. When the first tank is dumped, the second tank becomes the first. Fresh resist stripper is then added to the second tank.

Rinse Water Recycling

Currently, Plant A plumbs all its rinse water effluent directly into the collection sump. However, the plant may be able to recycle some of the rinse water solutions. For example, rinse systems that follow an acid process chemical bath, such as a peroxide/sulfuric acid etch, can sometimes be used for feed water to a rinse system that follows an alkaline cleaning bath. Implementation of such a system, however, should be done only after careful testing to make sure that addition of acid rinse water to the alkaline rinse bath does not cause problems with metal hydroxide precipitation on clean parts.

The configuration of Plant A's process lines may allow some of these rinse systems to be plumbed together in series. For example, rinse tank 14, which follows a sulfuric acid bath, could be plumbed into rinse tank 16, which appears to follow an alkaline cleaning bath. Based on data of the existing water used, rinse tanks 14 and 16 both use approximately 500 gallons each day. If 100 percent of the water used in rinse tank 14 could be used for rinsing operations in tank 16, 500 gallons of water could be saved each day. The plant would also reduce the volume of wastewater treated each day by 500 gallons and could, therefore, reduce treatment chemical usage and sludge generation. Rinse water could also be recycled if the rinse tanks were operated on a batch process.

Copper Sulfate Crystals

Plant A personnel indicated that they were unsure of how to handle the copper sulfate crystals generated at the plant. Currently, these crystals are disposed of offsite as a hazardous waste. One option available to the facility is to mix the crystals with the industrial waste treatment sludge. Since this sludge is sent to a reclaimer, the copper content in the crystals may bring Plant A a larger payment on reclaimed copper. This practice will also prevent Plant A from accumulating containers of crystals.

TREATMENT ALTERNATIVES

Waste reduction through alternative treatment can be achieved by modifying a treatment system to reduce the volume of hazardous waste generated. One of the treatment alternatives available to Plant A is segregation of waste streams, which is described earlier in this report. Another treatment alternative available to Plant A is sludge dewatering.

Sludge Dewatering

Wastewater treatment sludge generated at Plant A is dewatered by a gravity filter system. Although this type of dewatering can remove some of the free water in the sludge, it is not as effective as mechanical dewatering. Analytical data for the waste treatment sludge show that the gravity filter system can increase solids content to 11 percent. Mechanical dewatering equipment can achieve a solids content up to 35 percent for most industrial waste sludge. Figure A2 shows the decrease in sludge volume that can be achieved by increasing solids content. The figure shows that increasing the solids content from 10 percent to 35 percent reduces sludge volume from 80 gallons to 20 gallons.

Plant A now removes the sludge from the filter system and allows it to air dry in open drums. This has significantly reduced the sludge volume, according to Plant A personnel. However, this method of dewatering will not work during the rain season, and it also presents problems for complying with the 90-day accumulation limits placed on hazardous waste generators. Therefore, the use of a mechanical dewatering system may be beneficial for reducing sludge volume and also for complying with hazardous waste regulations.

Assuming a direct correlation between wastewater volume and sludge volume, Plant A could also reduce its sludge generation by 80 percent. This would equal three drums less each month at a savings at $50 per drum, or $150. Total savings for operating each rinse tank as a batch rinse system could be as great as $1020 each month.

Savings from reducing the flow rate of water through each rinse tank depends on the minimum flow rate that can be used to maintain adequate rinsing. In the Rinse Water Reduction section, it was shown that the present flow rate of 16 gallons per minute creates a ratio of process bath concentration to rinse solution concentration of 5,000 to 1. For illustration purposes, assume the flow rate could be reduced to 12 gallons per minute; ratio would be reduced to 3750 to 1. The rinsing requirements for Plant A rinse systems were not available to the consultants. However, since the standard ratio of process chemical concentration to rinse solution concentration used in the electroplating industry is approximately 1000 to 1, a 25 percent reduction in flow rate, which produces a 3750 to 1 ratio, appears achievable. If the flow rate could be reduced by 25 percent: (1) water and sewer fee savings would be $46 per month (based on a reduction in water usage of 34,600 gallons and water and sewer fees of $0.50 per 750 gallons each); (2) treatment chemical savings would be $210 per month (based on a 25 percent reduction in existing treatment chemical costs); and (3) sludge disposal cost savings would be $50 per month (based on a 25 percent reduction in sludge volume generated each month). Total savings would be approximately $310 per month.

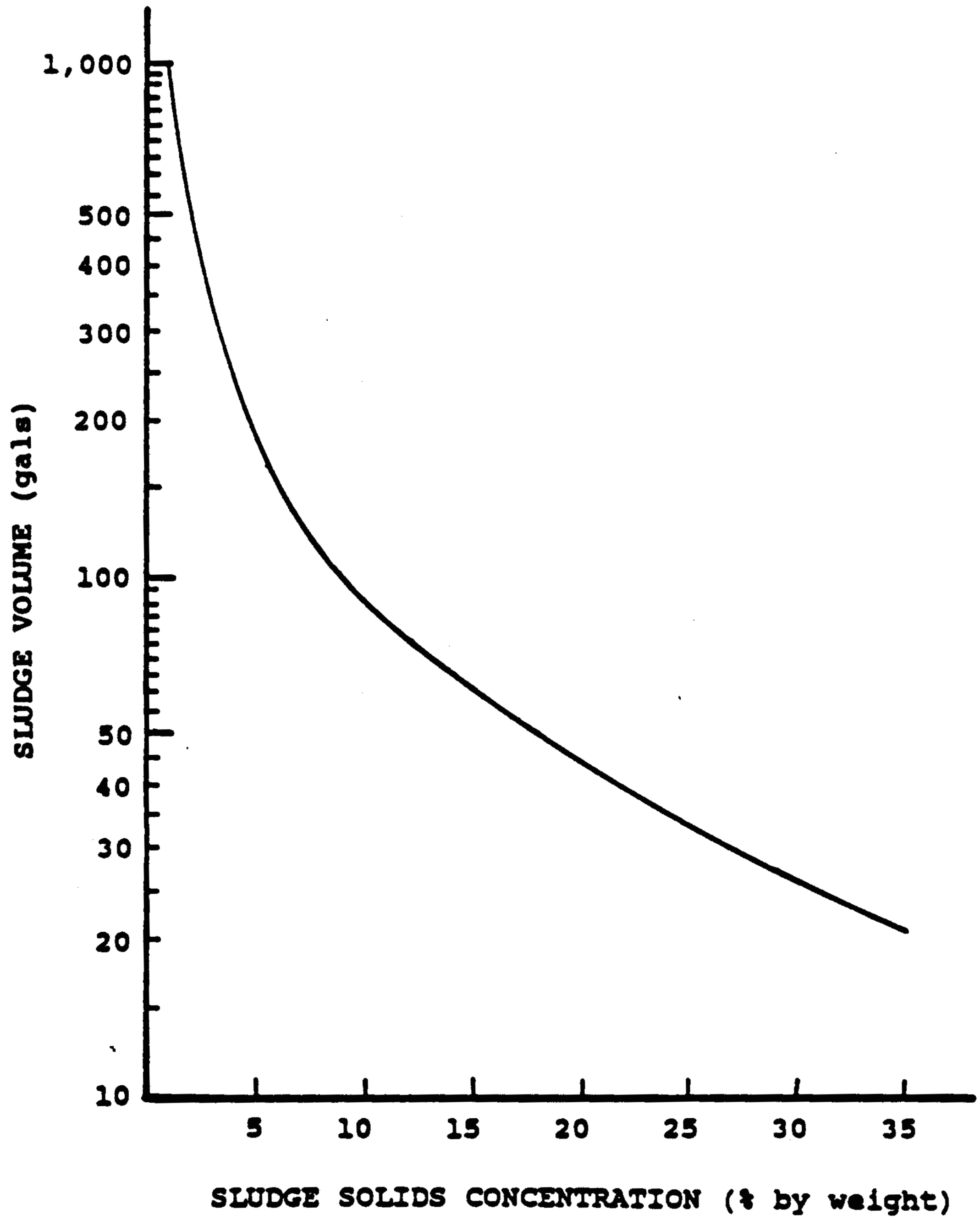


FIGURE A2 - SLUDGE VOLUME VS SLUDGE SOLIDS CONCENTRATION

The use of automated rinse water flow controls will require significant capital investment. A pH/conductivity meter used to automatically turn rinse water on and off will cost approximately $700 to purchase and install. If these controls were purchased for all nine rinse tanks, the total cost would be $6,300. Savings would depend on the reduction in water usage that could be achieved. Since drag-out rates for process baths and operating parameters for the rinse systems were not available, estimates on saving that can be achieved by installing automated flow controls cannot be calculated. However, one printed circuit board manufacturer estimated that water use was reduced by 67 percent by installing flow control meters. For illustrative purposes, a more conservative estimate of 25 percent reduction in water use will be used. Therefore, the use of automated flow control meters could also save Sun Circuits $310 per month. At that savings rate, payback on investment would take 21 months.

Feasibility Analysis Phase

The recommended options were evaluated for their technical and economic feasibility by the consultants, who obtained cost and performance data from vendors where new equipment was recommended. The result of the technical and economic feasibility analyses was a list of feasible options, which became part of the assessment's final report. The next waste minimization assessment phase, Implementation, was left to the discretion of the printed circuit board manufacturer, Plant A.

The specific economic aspects of implementing each of the source reduction/resource recovery options were not separately documented by Plant A. Most of the source reduction options employed are essentially good operating practices, and hence did not require a large capital investment. However, the rework strategies and their evolution did require a large R&D expenditure. The implementation of these measures seemed to be guided more by the intuition and foresight of the plant personnel than by the calculated benefits that may have been indicated by a specific detailed economic evaluation.

RINSE WATER REDUCTION

Operating the rinse tanks as batch rinse systems or reducing the rate of water flow through the rinse tanks can be implemented for minimal costs. To operate the rinse tanks as batch rinse systems, the plant would need additional labor to manually dump the rinse tanks. Flow restrictors for reducing the flow of water through rinse tanks would require only minor capital investments. The resulting savings in water usage, sewer fees, and treatment chemical costs would depend on the reduction in water use achieved.

Table A5 indicates that water usage can be reduced by 6,920 gallons per day, or approximately 80 percent, if all the rinse tanks were operated as batch rinse systems.

TABLE A5

RINSE WATER WASTE GENERATION

Operating as Flow-Through Tanks at a Rate of 16 gpm

Tank Number	Time Water is Running	Daily Flow Rate
2	96 minutes	1536 gallons
4	96 minutes	1536 gallons
7	96 minutes	1536 gallons
9	96 minutes	1536 gallons
10	96 minutes	1536 gallons
14	30 minutes	480 gallons
16	30 minutes	480 gallons
		8640 gallons

8640 gallons wastewater generated each day.

Operating as Batch Tanks Holding 30 Gallons of Rinse Water

Tank Number	Number of Batches Daily	Volume of Wastewater Generated Daily
2	12	360
4	12	360
6	12	360
8	12	360
10	12	360
14	2	60
16	2	60
		1720 gallons

1720 gallons generated each day.

Assuming 20 work days per month, water usage could be reduced by 138,400 gallons each month. Since both water usage and sewer discharge fees are approximately $0.50 per 750 gallons, Plant A would save approximately $190 each month on water and sewer fees by reducing water usage by 138,400 gallons. As stated in Section 2.3, Plant A spends approximately $850 each month on treatment chemicals. Therefore, an 80 percent reduction in wastewater generation could reduce treatment chemical costs by as much as 80 percent. This would amount to a savings of $680 each month. Actual treatment chemical savings may be less because the wastewater will have a higher contaminant concentration and thus may require greater treatment chemical feed rates per volume of wastewater. Reductions in sludge volume will depend on the efficiency of the treatment system and the actual reductions in treatment chemical usage.

The use of various drag-out reduction techniques will increase the potential for reducing rinse water usage because less process chemicals will enter the rinse system. By installing a bar rail above each process tank for hanging workpiece racks, the plant could allow for greater drainage time before rinsing. This bar could be installed by Plant A personnel for a few hundred dollars if constructed out of 1 inch PVC piping. Other drag-out reduction techniques such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration can be implemented for little cost. Savings associated with drag-out minimization cannot be quantified until the techniques are implemented.

EQUIPMENT CLEANOUT

Plant A can reduce waste nitric acid generation by using a multiple tank cleaning line. The costs associated with setting up such a system include the cost of additional tanks and the installation labor costs. The costs for setting up a cascade cleaning line would be approximately $350 per tank. Labor costs of $55 an hour for 4 hours would be $220.

The savings associated with a multiple tank plating rack cleaning line include reduced costs for nitric acid purchases and waste acid handling. The consultants visited one plant that used five 15-gallon tanks as a multiple stage cleaning line. The plant generates 15 gallons of waste nitric acid every 6 months. If Plant A could reduce its waste nitric acid generation from 60 gallons to 15 gallons per 6 months, it would achieve a savings of $140 in nitric acid purchases and $90 in waste disposal costs each 6 months. This is based on nitric acid costing approximately $3.10 per gallon and waste disposal costs being approximately $2.00 per gallon.

MATERIAL RECYCLING

The auditors identified three waste materials for recycling: (1) photoresist stripper waste, (2) acidic rinse water effluent, and (3) copper sulfate crystals. Decanting or filtering spent stripper waste so it can be reused will require minor purchases to set up a decantation system or a filter system. Savings would include fewer fresh stripper purchases and lower stripper waste disposal costs. If decantation or filtration could be used to extend the process bath life from 2 weeks to 4 weeks, Plant A could reduce stripper purchases by 30 gallons each month. Once the stripper becomes too dilute for continued use, it can be filtered once more and used in the treatment system for pH adjustment. This could save

Plant A $50 each month for disposal of stripper waste. A polymer sludge residue would still be generated, however.

To implement a system to reuse rinse water effluent from rinse tank 16 for feed water into rinse tank 14, Plant A would need to spend approximately $1,000. This includes $500 for contractor labor for 1 day and $500 for materials that include piping materials and a three-quarter horsepower pump, which would be adequate for a typical rinse system. Assuming that both rinse systems operate at the same flow rate, no storage tank capacity would be necessary.

Savings associated with recycling rinse water have been estimated based on Plant A's current water usage. Water and sewer fee savings would be approximately $13 each month based on a reduction in water usage of 500 gallons each day. Since wastewater generation would be reduced by 5 percent, treatment chemical usage could also be reduced by approximately 5 percent. A 5 percent reduction in the company's existing treatment chemical costs, which are $850 per month, would save Plant A $42 each month in treatment chemical purchases.

Copper sulfate crystals generated by Plant A could be recycled by adding them to the industrial waste sludge. There is no additional cost associated with mixing the crystals and the sludge since the crystals are also handled as hazardous waste if kept separate. Since the sludge is sent to a metal reclaimer, Plant A may be able to save money because the copper content of the sludge will be increased and, therefore, a larger payment for reclaimed metals will be received.

WASTE SEGREGATION

The costs and savings associated with segregating chelated and nonchelated waste streams will depend on the design requirements of the segregation and the modifications to the treatment system that can be made once the materials are segregated. Assuming segregation will only entail installing a 500-gallon storage tank, pumps, gauges, and necessary piping, equipment costs would range between $2,000 and $4,000. Double containment would be more expensive. In addition, installation costs may be as high as 100 percent of equipment costs.

As discussed in Section 5.1, the ferrous sulfate used to treat the wastewater contributes approximately 34 percent of the total sludge volume. The ferrous sulfate also costs Plant A approximately $250 each month to purchase. Savings associated with segregating chelated waste streams and batch treating them will depend on the percentage of ferrous sulfate usage that can be eliminated through batch treatment of chelated waste streams. Since information on which process chemicals contain chelators was not available to the audit team, development of segregation alternatives and estimates for material and waste disposal cost savings could not be developed.

SLUDGE DEWATERING

Small filter press units designed to handle from 0.75 to 3.75 gallons of sludge per load cost between $2,800 and $4,900. Assuming that Plant A already has a source of compressed air, the company can install the unit itself. The unit can handle 7.5 to 37.5 gallons of sludge per 5-day work week. These units can increase solids content from 1 percent to approximately 35 percent. Plant A's current bag filter dewatering unit can achieve a sludge solids concentration of 11 percent. An increase in solids concentration from 11 percent to 35 percent will reduce sludge volume by approximately 75 percent. This could reduce the plant's sludge generation from approximately 200 gallons to about 50 gallons per month. Since Plant A estimates that sludge disposal costs approximately $1.00 per gallon, this sludge dewatering could save the company approximately $150 each month in disposal costs.

SUMMARY

The audit of Plant A was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant A each month:

o Industrial waste sludge	-	Approximately 200 gallons
o Photoresist stripper waste	-	Approximately 60 gallons
o Copper sulfate crystals	-	Undetermined
o Nitric acid waste	-	Approximately 10 gallons
o Reflow oil	-	Undetermined

The audit provided information that is useful to identify several waste reduction techniques that may be feasible for Plant A to implement. The following waste reduction opportunities were identified:

- Use process chemistries that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- Use non-chelated process chemistries to replace chelated chemistries.
- Operate the rinse tanks as batch rinse systems.
- Reduce the flow rate used in the flow-through rinse tanks.
- Use flow restrictors and automated flow controls to reduce rinse water usage.
- Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- Install a multiple-stage electroplating rack cleaning line to reduce nitric acid waste generation.

- Reuse rinse water effluent from rinse systems following acidic baths as rinse water influent to rinse systems that follow alkaline cleaning baths.
- Mix copper sulfate crystals with industrial waste sludge for off-site metals reclamation.
- Segregate chelated waste streams from non-chelated waste streams and batch treat them.
- Dewater sludge using a mechanical filter press.

References

DHS. 1987. Waste Audit Study - Printed Circuit Board Manufacturers. June 1987. Prepared for California Department of Health Services, Alternative Technology Section (Sacramento, California) by Planning Research Corporation.

PLANT B WASTE MINIMIZATION ASSESSMENT

The waste minimization assessment of Plant B followed the same protocol used for Plant A, and included:

- o Planning and organization
- o Assessment phase
- o Feasibility analysis phase

Implementation of selected waste minimization options was left to the discretion of Plant B.

Planning and Organization

Planning and organization of the assessment were a joint effort of the consulting firm and the PC board manufacturing plant's operations manager. As summarized in Figure 1.1, this phase of the assessment involved getting company management commitment to the project, setting goals for the assessment, and establishing a task force (the consultants working in cooperation with the plant operations manager) to conduct the assessment.

Assessment Phase: Process and Facility Data

The consultants worked with the plant operations manager to establish a data base of the facility's raw material needs, materials handling procedures, and operations processes. Block flow diagrams were drawn up to identify where materials are used and where waste is generated. Initial study of this information and discussions of waste stream concerns at the plant served as preliminary steps to the site inspection, during which additional process and waste handling information was obtained.

FACILITY DESCRIPTION

Plant B is a prototype circuit board manufacturer specializing in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), photoresist printing, plating, etching, and stripping.

PROCESS DESCRIPTION

Figure B1 is a floor plan of the plant's plating and etching process area. The numbers listed in the floor plan represent the identification number for each process bath and rinse tank. Tables B1 and B2 describe Plant B's rinsing operations and chemical process baths, respectively.

The plant presently uses seven dip tanks and two spray rinse tanks. All the dip rinse tanks are equipped with pH/conductivity meters that control the flow of water through the rinse tanks. The spray rinse tanks are all operated with foot pedals for turning on the water.

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating, etching, and stripping processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, and industrial waste treatment, and equipment cleanout. This chapter describes the hazardous waste generating and handling activities performed at Plant B and describes the volume and characteristics of the hazardous wastes generated. Table B3 lists Plant B's hazardous waste management characteristics.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant B. Wastewater generation fluctuates between 7,000 to 11,000 gallons per day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge that is generated from this treatment is handled as a hazardous waste.

Spent Chemical Bath Dumping

When process chemical baths become too contaminated or diluted for use (spent), it is removed from the process tank. The spent chemical bath is then either containerized for reclamation by the manufacturer, containerized for off-site disposal, used as a neutralization chemical in the industrial waste treatment system, or dumped into the wastewater collection sump. A schedule for dumping each spent process bath was not available from Plant B, but plant personnel indicated that the frequency varies. A bath is changed when personnel recognize that the effectiveness of the bath is no longer adequate.

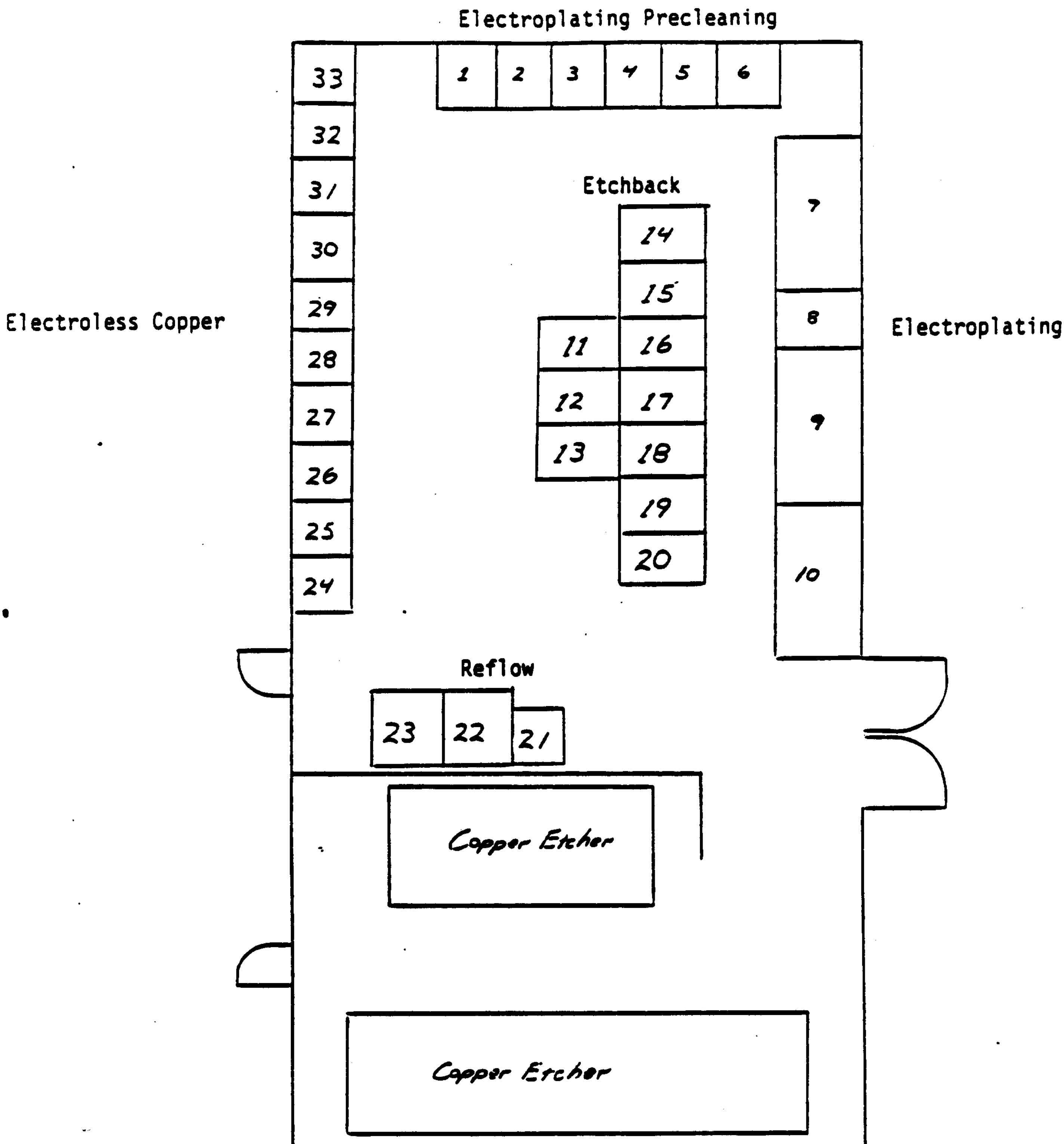


FIGURE B1

PLANT B'S ETCHING AND PLATING FACILITY

TABLE B1
RINSE SYSTEM INFORMATION

RINSE TANK/ NUMBER	RINSE WATER FLOW CONTROLS	NUMBER OF TANKS IN SYSTEM	COUNTER CURRENT SYSTEM	PROCESS BATH PRECEDING RINSE
Dip Rinse/1	pH/Conductivity Meters	one	no	Ammonium Bifluoride/2
Dip Rinse/3	pH/Conductivity Meters	one	no	MBL Cleaner/4
Dip Rinse/5	pH/Conductivity Meters	one	no	98% Sulfuric Acid/6
Dip Rinse/12	pH/Conductivity Meters	one	no	Black Oxide/11 and Tin Immerse/13
Drag-out/14	Manual Dumping	one	NA	---
Spray Rinse/15	Footpedals	one	NA	Drag-out Tank/14
Drag-out/18	Manual Dumping	one	NA	---
Spray Rinse/19	Footpedals	one	NA	Drag-out Tank/18
Dip Rinse/26	pH/Conductivity Meters	two	no	Rinse Tank/27
Dip Rinse/27	pH/Conductivity Meters	two	no	Catalyst
Dip Rinse/30	pH/Conductivity Meters	one	no	Sulfuric-Peroxide Etch/31
Dip Rinse/32	pH/Conductivity Meters	one	no	Cleaner-Conditioner /33

TABLE B2
PROCESS BATH INFORMATION

PROCESS BATH/ NUMBER	PROCESS BATH VOLUME (gallons)	METHOD OF DISPOSAL
Ammonium Bifluoride/2	50 gal.	To wastewater treatment facility
MBL Cleaner/4	50 gal.	To wastewater treatment facility
98% Sulfuric Acid/6	20 gal.	To wastewater treatment facility
Tin-Lead Bath/7	400 gal.	---
Fluorboric Acid/8	50 gal.	To wastewater treatment facility
Copper Sulfate/9	400 gal.	---
Copper Sulfate/10	400 gal.	---
Black Oxide/11	50 gal.	To wastewater treatment facility
Tin Immerse/13	50 gal.	To wastewater treatment facility
10% Sulfuric Acid/16	50 gal.	To wastewater treatment facility
Sulfuric/Peroxide Etch/17	50 gal.	To wastewater treatment facility
Soap Cleaner/20	50 gal.	To wastewater treatment facility
Reflow Flux/21	2 gal.	Off-site disposal
Reflow Oil/22	15 gal.	Off-site disposal
Reflow Oil/23	15 gal.	Off-site disposal
Electroless Copper/24	50 gal.	To wastewater treatment facility
Accelerator/25	50 gal.	To wastewater treatment facility
Catalyst/28	50 gal.	To wastewater treatment facility
Catalyst Prep/29	50 gal.	To wastewater treatment facility
Sulfuric-Peroxide Etch/31	50 gal.	To wastewater treatment facility
Cleaner-Conditioner/33	50 gal.	To wastewater treatment facility

TABLE B3. HAZARDOUS WASTE DATA

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Industrial Treatment Sludge	300 gal.	Off-site metal reclamation	$40/55 gal. drum	$240
Photoresist Stripper	---	Off-site disposal	$100/55 gal. drum	---
Nitric Acid	30 gal.	Off-site disposal	$100/55 gal. drum	$50
Reflow Oil	150 gal.	Off-site disposal	$100/55 gal. drum	$300

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods include containerizing spent baths for off-site disposal and dumping of spent chemical baths into the wastewater sump. The only process chemical baths containerized for disposal are the photoresist strippers and the reflow oil. Approximately 25 gallons of waste reflow oil is generated every 2 months. The volume of stripper waste generated was not estimated by Plant B. Chemical baths treated at the industrial waste treatment facility are transferred to one of the two wastewater sumps where the chemicals are neutralized. The waste is then fed into the industrial waste treatment system.

Copper sulfate crystals are also generated when some of the process baths are taken off-line. The crystals form in the process bath as the copper concentration increases. Before the process baths are dumped into the wastewater sump, the crystals are containerized as a solid waste since they cannot be fed into the treatment system. The crystals are mixed with the plant's industrial waste sludge, which is transported offsite for metal reclamation.

Industrial Wastewater Treatment

Plant B's industrial waste treatment facility treats all wastewater prior to discharge to the San Jose/Santa Clara Water Pollution Control Plant. Plant B's treatment facility removes metals and adjusts the pH of the wastewater to meet the maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/Santa Clara Water Pollution Control Plant. These maximum concentrations are as follows:

Chromium	1.0 mg/L
Copper	2.7 mg/L
Cyanide	1.0 mg/L
Lead	0.4 mg/L
Nickel	2.6 mg/L
Silver	0.7 mg/L
Zinc	2.6 mg/L

The treatment process includes neutralization, metals precipitation, filtration, and sludge dewatering. The treatment plant is located outside the main building in a curbed area. The metal hydroxide sludge generated by this treatment process is a hazardous waste. The treatment system generates approximately 25 gallons of sludge every month. The sludge dewatering unit produces a sludge that has a solids concentration of 35 percent. The sludge is transported offsite to World Resources of Phoenix, Arizona for metal reclamation. World Resources analyzes a sample from each load of sludge it receives. The analytical data provided by World Resources for the sludge generated by Plant B are as follows:

Percent solids - 35%

Metal content in pounds per dry ton

Copper	250
Nickel	11
Tin	59
Iron	12
Lead	22
Zinc	8

Equipment Cleanout

The primary source of hazardous waste associated with equipment cleanout is the cleaning of electroplating racks. Plant B uses nitric acid in a five tank cleaning line to clean electroplating racks. Each tank holds approximately 15 gallons of nitric acid. The acid in the first tank requires changing approximately every 6 months. When the nitric acid in the first tank is dumped, the remaining four tanks all move up one step in the cleaning line. The empty tank is filled with fresh nitric acid and is used as the last tank in the cleaning line. The waste nitric acid has too low a pH and too high a copper content to be treated in the industrial waste treatment system.

Other cleaning activities, such as floor washing and chemical bath tank rinsing, generate waste streams that discharge into the wastewater collection sump. According to Plant B personnel, these waste streams make up a small portion of the chemicals that enter the treatment system.

Assessment Phase: Option Generation

After the site inspection, the plant operations manager and the consultant team reviewed the raw material, process, and waste stream information and developed a number of waste minimization options for consideration. These options fall into the categories of source reduction techniques and recycling and resource recovery techniques.

SOURCE REDUCTION MEASURES

Plant B appears to have effectively implemented several technologies to reduce the volume of hazardous waste it generates. Water conservation techniques, such as rinse water flow control meters and pressure activated spray rinse tanks, are presently used at the plant. The industrial waste treatment system appears to effectively treat wastewater without producing excessive volumes of sludge. Plant B personnel stated that their effluent consistently meets the discharge requirements set by the San Jose/Santa Clara Water Pollution Control Plant. Also, the volume of sludge generated by the wastewater treatment system is lower than the volume generated at other manufacturing plants of comparable size and wastewater generation rates. For example, Plant B generates approximately 50 gallons of sludge every 2 months compared to another plant with a comparable wastewater generation rate that generates approximately 200 gallons of sludge every month. Nevertheless, several additional opportunities for waste reduction may be available to Plant B that can further reduce its hazardous waste generation. This section describes these opportunities.

MATERIAL SUBSTITUTION

Plant B may be able to reduce the volume of spent process chemicals and cleaning solutions containerized for off-site disposal by substituting materials. Two materials that Plant B handles as hazardous waste are spent reflow oil and spent nitric acid. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the Publicly Owned Treatment Works. Plant B could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from the cleaning of electroplating racks, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks during the cleaning process can be plated out in a tank equipped with a cathode and an anode. The metal stripped from the racks is plated onto the cathode and forms a metallic sludge that settles to the bottom of the cleaning tank. Once the solution becomes spent, it can be treated in the plant's industrial treatment system instead of being containerized for off-site disposal. Plant B should consult with chemical suppliers to identify alternative materials that can be recycled or treated and that will meet its specific operating requirements.

DRAG-OUT LOSS REDUCTION

Discussions with Plant B personnel indicated that little attention is placed on drag-out reduction. Although the plant does not generate excessive amounts of sludge, further reductions in sludge volume may be obtained by using drag-out reduction technologies. Reductions in drag-out loss should also have a direct impact on water usage. Since water flow through the rinse systems are controlled by pH/conductivity controls, drag-out reduction will decrease the frequency of rinse water flow through the rinse tanks. Plant B may be able to reduce drag-out by instituting operational modifications and training personnel in drag-out reduction techniques. Drag-out reduction techniques include slowing the workpiece rack withdrawal rates and increasing drainage time prior to rinsing. Other drag-out reduction methods include operating process baths at the lowest allowable concentration and using heated process baths when possible.

The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only. Plant B management should emphasize to process line operators that workpieces should be withdrawn slowly. An optimal removal rate can be determined by removing loaded workpiece racks from process baths at different rates and allowing the rack to drain into a catch basin. Drag-out volume can then be measured volumetrically.

Workpiece drainage also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath and place it in the rinse tank. However, installation of a bar or rail above the process tank may help ensure that adequate drainage time is provided prior to rinsing. Plant B has expressed concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Plant B should identify the processes that are not highly susceptible to oxidation and emphasize drag-out minimization techniques to personnel operating those processes.

RINSE WATER RECYCLING

Plant B may be able to recycle its rinse water by further treating effluent from the industrial waste treatment plant. This additional treatment may only require activated carbon treatment to remove trace organics from the water. Plant B should assess the need for other levels of treatment, such as ion-exchange or other technologies, based on the quality of the treated effluent. This recycled water would contain less natural contaminants, such as phosphates and carbonates, than tap water, which is presently used. Since these natural contaminants contribute to sludge volume because they precipitate during treatment, the use of recycled rinse water can reduce hazardous waste sludge generation and significantly reduce water usage and sewer discharge fees.

Feasibility Analysis Phase

After discussions with Plant B personnel, some of the options discussed in the previous section were selected for investigation of their technical and economic feasibility. The economic analysis was based on the raw material and waste disposal costs provided by the facility personnel and on economic and technical information provided by equipment manufacturers. The measures evaluated in this section include: material substitution, drag-out loss reduction and rinse water recycling.

MATERIAL SUBSTITUTION

The benefits associated with using recyclable and/or treatable process chemistries will depend on the costs of substitute materials compared with the costs of materials presently used. Also, additional process bath maintenance requirements and treatment costs need to be identified. These costs will depend on the type of substitute material chosen by Plant B.

Savings will include reduced waste disposal costs and material usage costs if the substitute material can be recycled. Plant B generates 150 gallons of waste reflow oil and 30 gallons of waste nitric acid annually. Since waste disposal costs for the waste reflow oil and waste nitric acid are both $100 per 55-gallon drum, which is the average cost for disposing of various liquid hazardous wastes according to PC board manufacturers, waste disposal cost savings would be approximately $300 per year for spent reflow oil and $50 per year for nitric acid waste. Actual savings associated with using recyclable reflow oil and nitric acid will depend on the difference in the cost of the substitute materials.

DRAG-OUT LOSS REDUCTION

Several drag-out minimization techniques can be implemented at Plant B for minimal costs. The use of a bar rail above each process tank for hanging workpiece racks will allow for greater drainage time before rinsing. This could be installed by Plant B's personnel for a few hundred dollars if constructed of 1 inch PVC piping. Other drag-out reduction techniques, such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration, can also be implemented for little cost. Developing a training program and emphasizing drag-out minimization will require time from management and operations personnel. Since information on drag-out rates and workpiece rack removal and drainage times were not available from Plant B, savings associated with drag-out minimization cannot be quantified prior to implementation.

RINSE WATER RECYCLING

Considerable capital investment may be needed to recycle wastewater for reuse in production. The costs associated with recycling treated wastewater effluent will depend on the level of additional treatment necessary to return the effluent back into the production processes. Other plants that are considering rinse water recycling have indicated that their primary concern is to remove organics from the treated effluent before reusing the water. An activated carbon system to treat the effluent can be used to remove organics from the water. If various anions and/or cations in the effluent must also be removed, treatment technologies such as reverse osmosis or ion-exchange may be required.

Information describing the rinse system operating parameters and the water quality or Plant B's treated effluent were not obtained during the audit. Therefore, treatment requirements for returning treated effluent to the rinse systems could not be developed. Plant B should investigate the potential for recycling rinse water by characterizing its rinse water effluent, determining the water quality needs for reusing treated effluent, and identifying potential technologies that can be used to treat the effluent for reuse.

The primary savings associated with recycling rinse water is lower water purchase and sewer discharge fees. Plant B generates approximately 7,000 to 11,000 gallons of wastewater each day. For an average daily water usage of 9,000 gallons, and assuming that 90 percent of the water can be recycled, Plant B could reuse approximately 8,000 gallons of water each day. Since water and sewer fees are both approximately $0.50 per 750 gallons, Plant B could save approximately $10 each day in water and sewer costs.

SUMMARY

The audit of the Plant B was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant B annually:

Industrial waste sludge	-	Approximately 300 gallons
Photoresist stripper waste	-	Undetermined
Copper sulfate crystals	-	Undetermined
Nitric acid waste	-	Approximately 30 gallons
Reflow oil	-	Approximately 150 gallons

The audit was used to identify several waste reduction techniques that may be feasible for Plant B to implement. The following waste reduction opportunities were identified:

- Use alternative reflow oil and electroplating rack stripper materials that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- Recycle treated effluent for reuse in the production process.

PLANT C WASTE MINIMIZATION ASSESSMENT

The waste minimization assessment of Plant C followed the same protocol used for Plant A, and included:

- o Planning and organization
- o Assessment phase
- o Feasibility analysis phase

Implementation of selected waste minimization options was left to the discretion of Plant C.

Planning and Organization

Planning and organization of the assessment were a joint effort of the consulting firm and the paint manufacturing plant's operations manager. As summarized in Figure 1.1, this phase of the assessment involved getting company management commitment to the project, setting goals for the assessment, and establishing a task force (the consultants working in cooperation with the plant operations manager) to conduct the assessment.

Assessment Phase: Process and Facility Data

The consultants worked with the plant operations manager to establish a data base of the facility's raw material needs, materials handling procedures, and operations processes. Block flow diagrams were drawn up to identify where materials are used and were waste is generated. Initial study of this information and discussions of waste stream concerns at the plant served as preliminary steps to the site inspection, during which additional process and waste handling information was obtained.

FACILITY DESCRIPTION

Plant C is a prototype circuit board manufacturer specializing in jobs involving limited production and fast turnaround. Manufacturing operations include drilling and routing, layering (for multilayer boards), plating, and etching.

PROCESS DESCRIPTION

Figure C1 is a floor plan of the plant's plating and etching process area. The numbers listed on the floor plan represent the identification number for each process bath and rinse tank. Tables C1 and C2 describe Plant C's rinsing operations and chemical process baths, respectively.

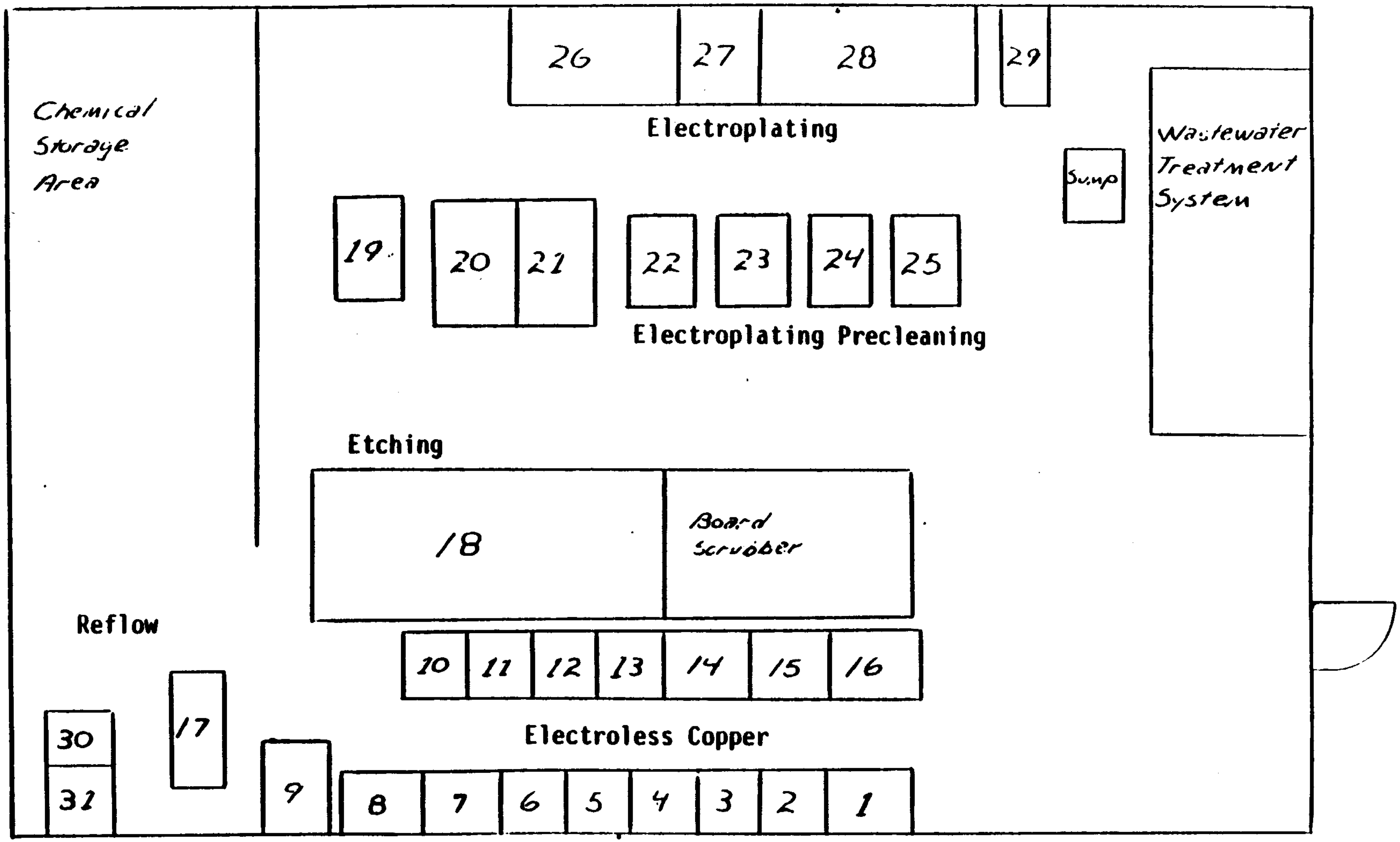


FIGURE C1

PLANT C'S ETCHING AND PLATING FACILITY

TABLE C1
RINSE SYSTEM INFORMATION

RINSE SYSTEM NUMBER	NUMBER OF TANKS	COUNTER CURRENT SYSTEM	PROCESS BATH PRECEDING RINSE SYSTEM
Dip Rinse/3	One	No	Soap Cleaner/2
Dip Rinse/5	Two	No	Peroxide Etchback/4
Dip Rinse/6	Two	No	Dip Rinse Tank/5
Dip Rinse/9	One	No	Catalyst/8
Dip Rinse/12	One	No	Electroless Copper/11
Dip Rinse/15	Two	No	Tin/Lead Stripper/14
Dip Rinse/16	Two	No	Dip Rinse Tank/5
Dip Rinse/20	Two	No	Micro Etch Cleaner/19
Dip Rinse/21	Two	No	Dip Rinse Tank/20
Drag-out/27	One	No	Copper Sulfate/26
Drag-out/29	One	No	Tin-Lead/28
Dip Rinse/30	Two	No	Reflow Oil/17
Dip Rinse/31	Two	No	Reflow Oil/17

TABLE C2
PROCESS BATH INFORMATION

PROCESS BATH/ IDENTIFICATION NUMBER	PROCESS BATH VOLUME IN TANK	METHOD OF DISPOSAL
Nickel Sulfate/1	30 gal.	Discharge to treatment facility
Soap Cleaner/2	30 gal.	Discharge to treatment facility
Peroxide Etchback/4	30 gal.	Discharge to treatment facility
10% Hydrochloric Acid/7	30 gal.	Discharge to treatment facility
Catalyst/8	30 gal.	Replenished, not disposed
Accelerator/10	30 gal.	Discharge to treatment facility
Electroless Copper/11	30 gal.	Replenished, not disposed
10% Hydrochloric Acid/13	30 gal.	Discharged to treatment facility
Tin/Lead Stripper/14	30 gal.	Discharged to treatment facility
Reflow Oil/17	20 gal.	Off-site disposal
Ammonium Etchant/18		Recycled by manufacturer
Micro Etch Cleaner/19	50 gal.	Discharged to treatment facility
Sulfuric Acid/22	50 gal.	Discharged to treatment facility
Fluorboric Acid/23	50 gal.	Discharged to treatment facility
Solder Bright/24	50 gal.	Discharged to treatment facility
Nitric Acid/25	50 gal.	Off-site disposal
Copper Sulfate/26	400 gal.	Replenished, not disposed
Tin-Lead/28	400 gal.	Replenished, not disposed

WASTE DESCRIPTION

Production activities that generate hazardous waste are the plating and etching processes. The sources of waste from these activities are rinsing operations, spent process bath dumping, industrial waste treatment, and equipment cleanout. This chapter of the report describes the hazardous waste generating and handling activities performed at Plant C and describes the volume and characteristics of the hazardous wastes generated. Table C3 lists Plant C's hazardous waste management characteristics.

Rinsing Operations

Rinsing operations associated with the chemical process lines are the major source of wastewater at Plant C. Facility personnel estimate that approximately 3,000 gallons of wastewater are generated each day. The rinse operations contribute to hazardous waste generation because waste rinse water carries away chemicals which are then removed by treatment at the industrial waste treatment plant. The sludge waste that is generated from this treatment is then handled as a hazardous waste.

The plant uses 11 dip rinse tanks that discharge to the industrial waste treatment plant and two drag-out tanks that are periodically dumped manually into the wastewater sump. All of the rinse tanks are plumbed directly to the wastewater treatment system via a collection sump. Discussions with facility personnel indicate that water flows through the dip rinse tanks only when the process line associated with the tank is in operation. Water flow for each rinse tank is turned on and off manually by production personnel. Plant C installed flow restrictors in each rinse system's water inflow line to control water usage.

TABLE C3
HAZARDOUS WASTE DATA

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
Spent Ion Exchange Resin	1200 gal.	Transported off-site for disposal	$2.00/gal.	$2,400
Nitric Acid	480 gal.	Transported off-site for disposal	$2.00/gal.	$ 960
Reflow Oil	240 gal	Transported off-site for disposal	$2.00/gal.	$ 480
Copper Sulfate Crystals	Undetermined	Transported off-site for disposal	$2.00/gal.	---

Four of the rinsing operations are double rinse tank system (tanks 5 and 6, tanks 15 and 16, tanks 21 and 22, and tanks 30 and 31). These four rinse systems, however, are not plumbed in series as counter-current rinse systems. Instead, each tank has a separate rinse water influent and effluent water line.

Spent Chemical Bath Dumping

When process chemical baths become too contaminated or diluted for use (spent), they are removed from the process tank. The spent chemical bath is then either containerized for reclamation by the manufacturer, containerized for off-site disposal, or dumped into the wastewater collection sump. A schedule for dumping each spent process bath was not available from Plant C, but plant personnel indicated that the frequency varies. A bath is changed when personnel recognize that the effectiveness of the bath is no longer adequate.

Only two of the spent bath handling methods contribute to the amount of hazardous waste generated at the plant. These methods are containerizing waste for off-site disposal and dumping of spent chemical bath into the wastewater sump. The process chemical bath containerized for disposal is the reflow oil. The plant generates approximately 20 gallons of waste reflow oil each month.

Other process baths are discharged to the treatment plant when they are spent (except for the etchant, which is sent back to the supplier for reclaim). Copper sulfate crystals are also generated when some of the process baths, such as the peroxide/sulfuric etch, are taken off-line. The crystals form in the process bath as the copper content increases. Before the process baths are dumped into the wastewater sump, the crystals are removed and containerized as a solid hazardous waste since they cannot be fed into the treatment system. Plant C did not estimate the volume of copper sulfate crystals generated each month.

Industrial Wastewater Treatment

Plant C's industrial waste treatment facility treats all wastewater prior to discharge to the San Jose/Santa Clara Water Pollution Control Plant. Plant C's treatment facility removes metals and adjusts the pH of the wastewater to meet the maximum allowable concentration of metals in the discharged effluent, as set by the San Jose/Santa Clara Water Pollution Control Plant. These maximum concentrations are as follows:

Chromium	1.0 mg/L
Copper	2.7 mg/L
Cyanide	1.0 mg/L
Lead	0.4 mg/L
Nickel	2.6 mg/L
Silver	0.7 mg/L
Zinc	2.6 mg/L

The treatment process includes filtration, ion-exchange, and neutralization. The ion-exchange (IE) system was recently installed to replace Plant C's conventional precipitation/clarifier treatment system. The Ion Exchange unit has a treatment capacity of 12 to 14 gallons per minute. The Ion Exchange unit produces less hazardous waste than the old treatment system. The hazardous waste generated by the Ion Exchange treatment process is spent ion-exchange resin. Approximately 100 gallons of waste resin are generated each month, compared to approximately 300 gallons of sludge generated by the old treatment system.

Equipment Cleanout

The primary source of hazardous waste associated with equipment cleanout is the cleaning of the copper etching tank, the tanks used in the electroplating line, and the electroplating racks. This equipment is cleaned by using nitric acid. Plant C estimates that approximately 40 gallons of waste nitric acid are generated each month. The waste nitric acid has too low of a pH and too high of a copper content to be discharged to the treatment facility.

The nitric acid solution is stored in a single 50-gallon tank where electroplating racks can be immersed in the solution for cleaning. The nitric acid is used to strip the copper, tin, and lead from the equipment. When the acid loses its ability to effectively oxidize the metal, it is containerized for disposal. Electroplating rack cleaning is the greatest source of waste nitric acid.

Assessment Phase: Option Generation

After the site inspection, the plant operations manager and the consultant team reviewed the raw material, process, and waste stream information and developed a number of waste minimization options for consideration. These options fall into the categories of source reduction techniques and recycling and resource recovery techniques.

SOURCE REDUCTION MEASURES

Plant C appears to have effectively implemented several technologies to reduce the volume of hazardous waste it generates. Water conservation techniques such as rinse water flow restrictors are presently used at Plant C, the plant's water use appears to be significantly lower than that of other plants of comparable size and production. For example, two other plants visited by the consultant generate approximately 10,000 gallons of wastewater each day compared to 3,000 gallons generated by Plant C each day. The ion exchange treatment system effectively treats wastewater without producing a hazardous waste sludge. This new treatment system produces approximately 100 gallons of spent ion exchange resin each month, with no sludge generated; the old treatment facility produced approximately 300 gallons of sludge each month. Nevertheless, several additional opportunities for waste reduction may be available to Plant C to further reduce its hazardous waste generation. This section describes these opportunities.

Material Substitution

Plant C may be able to reduce the volume of spent process chemicals and cleaning solutions containerized for off-site disposal by substituting materials. Two materials that Plant C handles as hazardous waste are spent reflow oil and spent nitric acid. Several reflow oil products are available that, when spent, either can be returned to the supplier for recycling or can be treated by the facility prior to discharge to the Publicly Owned Treatment Works. Plant C could eliminate a hazardous waste stream by replacing its present reflow oil with a recyclable or treatable reflow oil.

Nitric acid waste, which is generated from equipment cleanout, can also be eliminated by using an alternative cleaning solution. One chemical supplier offers an electroplating rack cleaning solution that can be regenerated. The metal stripped off of racks during the cleaning process can be plated out in a tank equipped with a cathode and an anode. In this method, metal stripped from the racks is plated onto the cathode and forms a metallic sludge that settles to the bottom of the cleaning tank. Once the solution becomes spent, it can be treated in the plant's industrial treatment system instead of being containerized for off-site disposal. Plant C should consult with chemical suppliers to identify alternative materials that can be recycled or treated and that will meet its specific operating requirements.

RINSE WATER REDUCTION

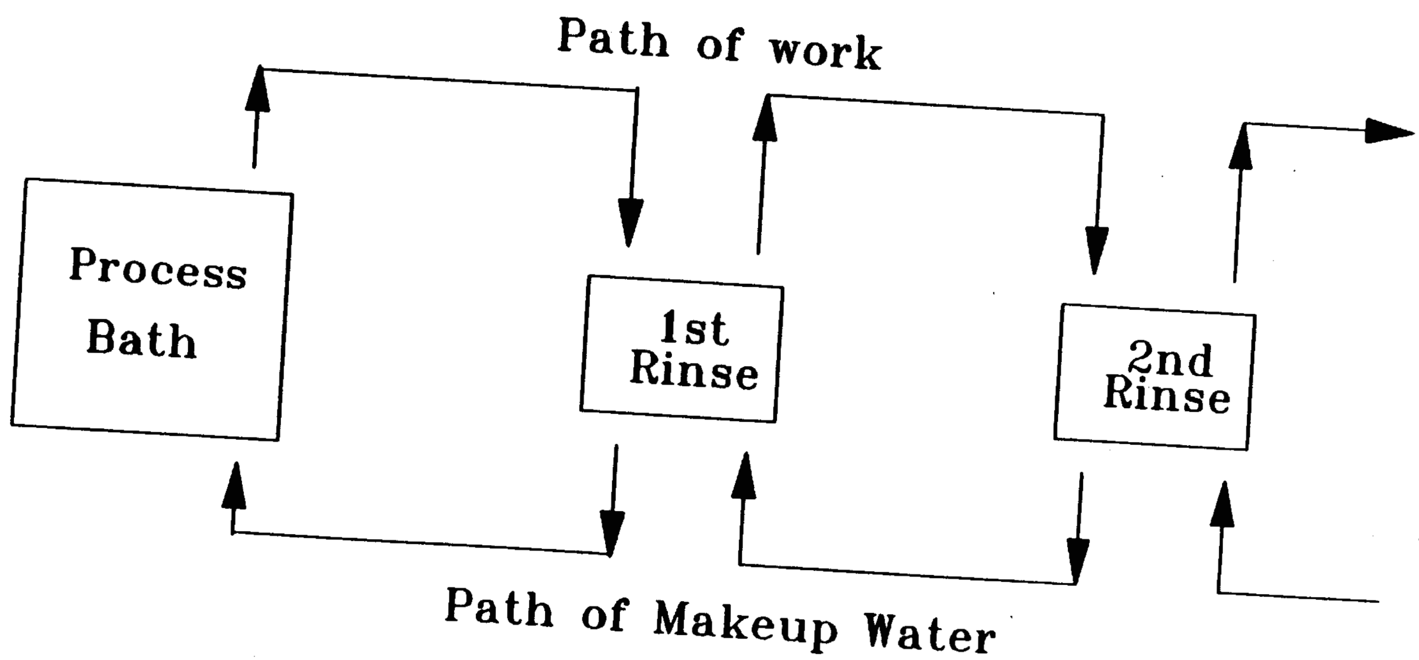
Plant C can reduce rinse water usage, as well as reduce the quantity of hazardous chemicals entering the waste stream, by converting several of its double tank rinse systems into two-stage, closed circuit counter-current rinse systems. By reducing water usage and quantity of chemical wastes, the load on the treatment system will be reduced and the longevity of the ion exchange resin can be increased. The plant currently uses four double tank rinse systems (tanks 5 and 6, tanks 15 and 16, tanks 20 and 21, and tanks 30 and 31; see Figure C1). Each tank, however, is plumbed separately. If the two tanks associated with each of the four rinse systems were plumbed in series as counter-current rinse systems, the plant could significantly reduce its rinse water use. Figure C2 illustrates the set-up for a two stage counter-current rinse system.

Plant C did not provide data on the flow rate used for each rinse tank. Therefore, calculations on actual water use savings cannot be presented. However, the following example illustrates how a counter-current rinse system can reduce water use compared with the present rinse system used at the plant. A facility operates a two stage rinse system with: (1) each tank having a separate water inflow line; (2) a water flow rate of 10 gallons per minute; and (3) the rinse water for the system turned on a total of 120 minutes per day. The total water usage for this system would be 2,400 gallons per day. The following equation can be used to illustrate how a two stage counter-current system could reduce rinse water usage at the facility:

$$Q = [(C_p/C_r)^{1/n} + 1/n]D$$

FIGURE C2

MULTIPLE CLOSED CIRCUIT
COUNTERFLOW RINSE SYSTEM



Q = rinse tank flow rate
D = drag-out rate
C_p = chemical concentration on process solution
C_r = allowable chemical concentration in rinse solution
n = number of rinse tanks in series

Several assumptions must be made to use this equation. These are as follows:

- o The concentration of chemicals in the rinse solution cannot exceed 1/1000 of the concentration of chemicals in the process bath. This value is a common parameter used in the electroplating industry for rinse water contaminant concentration.

- o The drag-out rate of chemicals used for manufacturing printed circuit boards is approximately 15 ml/ft^2 of board. This value is a standard approximation used for estimating drag-out created by a printed circuit board.

- o An average workpiece rack holds approximately 2.5 ft^3 of boards (example: 30 4-inch by 3-inch boards).

The drag-out rate for each workpiece rack is:

$$15 \text{ ml} \times 2.5 \text{ ft}^3 = 37.5 \text{ ml.}$$

Converted to gallons, drag-out equals 0.01 gallon.
By substituting the values into the equation:

$$[(1000)^{1/2} + 1/2]\ 0.01 \text{ gallons/minute} = 0.32 \text{ gallon/minute.}$$

Therefore, if the facility converted its existing rinse system into a two-stage closed circuit counter-current rinse system, it could reduce the flow rate from 10 gallons per minute through each tank to 0.32 gallon per minute through both tanks. This would in theory reduce the daily water usage from 2,400 gallons to 38 gallons and would significantly reduce the quantity of hazardous chemicals entering the shop's treatment system. The actual volume of rinse water reduction that can be achieved by Plant C depends on the drag-out rate from the plant's process baths and the rinse system parameters for the four double rinse tank systems.

DRAG-OUT LOSS REDUCTION

Discussions with Plant C personnel indicated that little attention is placed on drag-out reduction. The plant may be able to generate less spent ion-exchange resin by using drag-out reduction technologies. Reductions in drag-out loss should also have a direct impact on water usage. Since water flow through the rinse systems are controlled by pH/conductivity controls, drag-out reduction will decrease the frequency of rinse water flow through the rinse tanks. Plant C may be able to reduce drag-out by instituting operational modifications and training personnel in drag-out reduction techniques. Drag-out reduction techniques include slowing workpiece rack withdrawal rates and increasing drainage time prior to rinsing. Other drag-out reduction methods include operating process baths at the lowest allowable concentration and using heated process baths when possible.

The faster an item is removed from the process bath, the thicker the film on the workpiece surface and the greater the drag-out volume will be. The effect is so significant that most of the time allowed for withdrawal and drainage of a rack should be used for withdrawal only. Plant C management should emphasize to process line operators that workpieces should be withdrawn slowly. An optimal removal rate can be determined by removing loaded workpiece racks from process baths at different rates and allowing the racks to drain into a catch basin. Drag-out volume can then be measured volumetrically.

Workpiece drainage also depends on the operator. The time allowed for drainage can be inadequate if the operator is rushed to remove the workpiece rack from the process bath and place it in the rinse tank. However, installation of a bar or rail above the process tank may help ensure that adequate drainage time is provided prior to rinsing. Other printed circuit board manufacturers have expressed concern that increasing workpiece rack removal and drainage time will allow for chemical oxidation on the board. Plant C should identify the processes that are not highly susceptible to oxidation and emphasize drag-out minimization techniques to personnel operating those processes.

EQUIPMENT CLEANOUT

Plant C generates approximately 40 gallons of waste nitric acid every month from equipment cleanout. Plant C may be able to reduce the volume of nitric acid generated by modifying the existing cleaning methods.

One method for reducing the volume of waste nitric acid produced is to setup a workpiece rack cleaning line with several small tanks of nitric acid. The cleaning line is then used like a multi-stage rinse system. The first tank contains the most contaminated nitric acid solution, and the final tank in the cleaning line contains the freshest nitric acid. When the first tank no longer performs adequate initial cleaning, it is containerized for disposal (or used as initial cleaning solution for tank cleanout). Then the second tank in the cleaning line becomes the first. The empty tank is then filled with fresh nitric acid and it becomes the last tank in the cleaning line.

The use of a multi-stage rinse system can provide significant reductions in waste cleaning solution generation. One printed circuit board manufacturing plant uses a five-stage multiple tank cleaning line and only generates approximately 15 gallons of waste nitric acid each 6 months.

RINSE WATER RECYCLING

Plant C may be able to recycle its rinse water by further treating effluent from the industrial waste treatment plant. This additional treatment may only require activated carbon treatment to remove trace organics from the water. This recycled water would contain less natural contaminants, such as phosphates and carbonates, than the tap water that is presently used. Since these natural contaminants contribute to ion-exchange resin use because they are removed during treatment, recycling of rinse waters can reduce spent resin generation and significantly reduced water usage and sewer discharge fees.

Feasibility Analysis Phase

After discussions with Plant C personnel, some of the options discussed in the previous section were selected for investigation of their technical and economic feasibility. The economic analysis was based on the raw material and waste disposal costs provided by the facility personnel and on economic and technical information provided by equipment manufacturers. The measures evaluated in this section include: material substitution, rinse water reduction, drag-out loss reduction, equipment cleanout reduction and rinse water recycling.

MATERIAL SUBSTITUTION

The benefits associated with using recyclable and/or treatable process chemistries will depend on the costs of substitute materials compared with the costs of materials presently used. Also, additional process bath maintenance requirements and treatment costs need to be identified. These costs will depend on the type of substitute material chosen by Plant C.

Savings will include reduced waste disposal costs and material usage costs if the substitute material can be recycled onsite. Plant C generates approximately 250 gallons of waste reflow oil and 500 gallons of waste nitric acid annually. Since waste disposal costs for the waste reflow oil and waste nitric acid are both $100 per 55-gallon drum, which is the average cost for disposing of various liquid hazardous wastes according to circuit board manufacturers, waste disposal cost savings would be approximately $500 per year for spent reflow oil disposal and $1,000 per year for nitric acid waste. Actual savings associated with using recyclable reflow oil and nitric acid will depend on the difference in cost of the substitute materials.

RINSE WATER REDUCTION

The costs associated with converting the plant's four double tank rinse systems into two stage counter-current rinse systems would be minimal. Since the pairs of tanks are already next to each other, the only modifications necessary would be to re-plumb each rinse system. This could be done by Plant C personnel for less than a few hundred dollars. Savings would include reduced water use and sewer fees and reduced ion exchange resin purchases. Since rinse water flow rates, drag-out rates, and rinse system operating parameters were not available, we could not calculate estimates on savings in water use, sewer fees, and ion exchange resin purchases.

DRAG-OUT LOSS REDUCTION

The use of a bar rail above each process tank for hanging workpiece racks will allow for greater drainage time before rinsing. This could be installed by Plant C's personnel for a few hundred dollars if constructed of 1 inch PVC piping. Other drag-out reduction techniques, such as slowing workpiece rack removal rates and operating process baths at the lowest possible concentration, can also be implemented for little cost. Developing a training program and emphasizing drag-out minimization will require time from management and operations personnel. Since information on drag-out rates and workpiece rack removal and drainage times were not available from Plant C, savings associated with drag-out minimization cannot be quantified prior to implementation.

EQUIPMENT CLEANOUT REDUCTION

Plant C can reduce waste nitric acid generation by using a multiple tank cleaning line. The costs associated with setting up such a system include the cost of additional tanks and the installation labor costs. The costs for setting up a cascade cleaning line would be approximately $350 per tank. Labor costs of $55 an hour for 4 hours would be $220.

The savings associated with a multiple tank plating rack cleaning line include reduced costs for nitric acid purchases and waste acid handling. Plant C now generates approximately 480 gallons of waste nitric acid annually. The consultants visited one plant that used five 30-gallon tanks as a multiple stage cleaning line. That plant generates 30-gallons of waste nitric acid each year. If Plant C could reduce its waste nitric acid generation down to 30 gallons per year, it would achieve an annual savings of approximately $1,400 in nitric acid purchases and $800 in waste disposal costs. This assumes that nitric acid costs $3.10 per gallon and waste disposal costs are $100 per 55-gallon drum.

RINSE WATER RECYCLING

Considerable capital investment may be needed to recycle wastewater for reuse in production. The costs associated with recycling treated wastewater effluent will depend on the level of additional treatment necessary to return the effluent back into the production processes. Other plants that are considering rinse water recycling have indicated that their primary concern is to remove organics from the treated effluent before reusing the water. An activated carbon system to treat the effluent can be used to remove organics from the water. Waste treatment effluent data for the plant were not available from Plant C. Therefore, specific treatment requirements for recycling treated effluent could not be identified. Plant C should investigate the potential for recycling rinse water by characterizing its rinse water effluent, determining the water quality needs for reusing treated effluent, and identifying potential technologies that can be used to treat the effluent for reuse.

The primary savings associated with recycling rinse water are lower water purchase and sewer discharge fees. Plant C generates approximately 3,000 gallons of wastewater each day. Assuming that 90 percent of the water can be recycled, Plant C could reuse approximately 2,700 gallons of water each day. If water and sewer fees are both $0.5 per

750 gallons, Plant C could save approximately $75 each month in water and sewer costs, assuming a 20-day work month.

SUMMARY

The audit of Plant C was performed to identify opportunities for waste reduction. The following hazardous wastes are generated by Plant C each month:

Spent Ion Exchange Resin	-	Approximately 100 gallons
Copper Sulfate Crystals	-	Undetermined
Nitric Acid Waste	-	Approximately 40 gallons
Reflow Oil	-	Approximately 20 gallons

The audit provided information that was used to identify several waste reduction techniques that may be feasible for Plant C to implement. The following waste reduction opportunities were identified:

- o Use alternative reflow oil and electroplating rack stripper materials that can be recycled or treated when they are spent instead of chemistries that currently are containerized for off-site disposal.
- o Aggressively pursue drag-out reduction by developing operational procedures and training personnel to slowly remove workpiece racks and increase drainage time prior to rinsing.
- o Convert the four double tank rinse systems into two-stage counter-current rinse systems.
- o Install a multiple stage electroplating rack cleaning line to reduce nitric acid waste generation.
- o Recycle treated effluent for reuse in the production process.

APPENDIX TWO

WHERE TO GET HELP:

FURTHER INFORMATION ON WASTE MINIMIZATION

Additional information on source reduction, reuse and recycling approaches to waste minimization is available in EPA reports listed in this section, and through state programs (listed below) that offer technical and/or financial assistance in the areas of waste minimization and treatment.

In addition, waste exchanges have been established in some areas of the U.S. to put waste generators in contact with potential users of the waste. Four waste exchanges are listed below. Finally, EPA's regional offices are listed.

EPA REPORTS ON WASTE MINIMIZATION

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex." Executive Summary.*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste for Parts Cleaning and from Electronic Capacitor Manufacturing Operation." Executive Summary.*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Cyanide Wastes from Electroplating Operations." Executive Summary.*

U.S. Environmental Protection Agency. Report to Congress: Waste Minimization, Vols. I and II. EPA/530-SW-86-033 and -034 (Washington, D.C.: U.S. EPA, 1986).**

U.S. Environmental Protection Agency. Waste Minimization - Issues and Options, Vols. I-III EPA/530-SW-86-041 through -043. (Washington, D.C.: U.S. EPA, 1986).**

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* Executive Summary available from EPA, PPRB, RREL, 26 West Martin Luther King Drive Cincinnati, OH, 45268; full report available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA 22161.

** Available from the National Technical Information Service as a five-volume set, NTIS No. PB-87-114-328.

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CHAPTER 1.0

SUMMARY AND CONCLUSIONS

The objectives of the waste reduction study for the printed circuit board manufacturing industry were to identify waste reduction technologies available to the industry and to develop a waste reduction audit protocol that can be used by a PC board manufacturer to assess its own waste reduction opportunities. The emphasis of the study was to identify waste reduction technologies available to small- to medium-sized manufacturing firms. To meet the objectives, PRC performed waste audits at three PC board manufacturing plants.

1.1 INDUSTRY DESCRIPTION

The PC board manufacturing industry uses production processes similar to those of the electroplating and metal finishing industry. As a result, many of the waste reduction technologies available to the electroplating and metal finishing industries can be applied to the PC board manufacturing industry.

Typical hazardous waste streams generated by a PC board manufacturer are as follows:

- Industrial waste treatment sludge
- Spent process baths
- Acids used for equipment cleaning
- Copper sulfate crystals

1.2 WASTE REDUCTION TECHNOLOGIES

Waste reduction technologies available to the PC board industry are classified as follows:

- Source reduction
- Recycling and resource recovery

- Alternative treatment

Source reduction includes waste reduction technologies designed to reduce the volume of wastes initially generated. Source reduction is usually the least expensive approach to minimizing waste. Many of the source reduction options available to the PC board manufacturing industry require only housekeeping changes or minor in-plant process modifications.

Recycling and resource recovery includes directly using a waste as a raw material for another process or recovering valuable materials from a waste stream before the waste is disposed of. Opportunities for both direct use of waste materials and the recycling of materials from a waste stream are available to the PC board manufacturing industry.

Treatment alternatives associated with waste reduction include the treatment of waste streams to reduce their volume or hazard, source segregation to allow for selective waste treatment, and treatment process modifications to reduce the volume of the resultant waste stream.

There are many technologies within the three waste reduction categories that are available to the PC board manufacturing industry. Examples of these technologies are described as follows:

1.2.1 Source Reduction

- The use of non-chelated process chemistries as opposed to chelated chemistries can reduce the volume of industrial waste treatment sludge.

- Recyclable process chemistries can be used in the PC board manufacturing process.

- Reducing the volume of water used for rinsing operations will reduce the volume of industrial waste sludge generated during wastewater treatment. A variety of rinse water reduction techniques are available including:

  - Using of spray rinse systems

  - Creating agitation in the rinse tank by forced air or water, or agitating a work piece rack in the rinse tank

  - Using multiple stage counter-current rinse systems

- Installing flow restrictors and flow control valves to regulate water usage

- o Reductions in drag-out loss can reduce the concentration of chemicals in the wastewater and, therefore, reduce the volume of sludge generated during wastewater treatment. Several drag-out reduction techniques are available including:

  - Operating process baths at the lowest possible chemical concentrations

  - Operating process baths at higher temperatures

  - Withdrawing work piece racks at a slower rate

  - Draining work piece racks for a longer period of time

  - Capturing drag-out on a drainage board that drains back into the process tank

  - Adding wetting agents to process baths to reduce the surface tension of the process bath solution and, therefore, reduce the thickness of the drag-out film on the work piece

  - Recovering process chemicals in a drag-out tank and replenishing the process bath with the recovered solution

- o Equipment cleaning solution wastes can be reduced through the use of multiple stage cleaning lines.

1.2.2 Recycling and Resource Recovery

- o Rinse water effluent from one rinse system can be reused as rinse water influent to another rinse system.

- o Material reuse techniques can be implemented. For example, spent acid or alkaline cleaners can be used for pH adjustment in the industrial waste treatment system.

- o Regeneration of spent process bath solutions can be used to recycle valuable etchants.

- o Copper sulfate crystals, formed when various spent etchants are cooled, can be used to replenish copper electroplating baths.

- o Spent photoresist stripper wastes can be recycled by decanting off the stripper solution to separate it from the polymer residue that forms as the solution is used.

- o Process bath chemicals and rinse water solutions can be recycled through use of chemical recovery technologies, including:

- Evaporation
- Reverse osmosis
- Ion exchange

o Technologies, such as electrolysis, are available for recovering metals from wastewater.

o Rinse water can be recycled by using reverse osmosis or ion exchange technologies.

1.2.3 Treatment Alternatives

o Prior treatment of water supply to rinsing operations can reduce the volume of sludge generated.

o The use of alternative treatment chemicals such as caustic soda and polyelectrolyte coagulants can reduce the volume of sludge generated.

o Waste segregation can improve the efficiency of a waste treatment system by separating various waste streams for selective treatment.

o Sludge dewatering equipment that can increase solids concentrations in sludge from 1 percent to 35 percent can cause an 8-to-1 reduction in sludge volume. Sludge dryers, which can increase solids content from 35 percent up to 90 percent, can reduce sludge volumes by approximately a 3-to-1 ratio.

o Alternative treatment systems such as ion exchange, which do not use the standard precipitation/ clarification method to remove pollutants, can eliminate the generation of heavy metal sludge.

1.3 ECONOMICS

The costs associated with implementing various waste reduction technologies is an important consideration for determining the feasibility of implementing a waste reduction technique.

In general, source reduction techniques are the least expensive to implement. Often housekeeping changes and minor process modifications can be accomplished with little if any capital investment. Recycling and resource recovery technologies and alternative treatment methods can vary in implementation costs. Many of these technologies can be implemented for less than $1,000, while others can cost more than $20,000.

The cost of implementation must be evaluated in comparison to the benefits. The benefits that can be obtained from waste reduction include reduced material costs, reduced waste disposal costs, and reduced liabilities associated with handling and disposing of hazardous wastes. The cost/benefit assessment for the various waste reduction technologies is, therefore, plant specific.

In general, expensive waste reduction technologies are less applicable to small companies than to large companies. This is primarily due to the limitations on benefits that a small company can achieve. For example, a large firm may find that a copper recovery unit is economically justifiable based on the amount of metal that can be recovered, the amount of treatment chemicals that can be saved, and volume of sludge that will no longer be generated. However, a small company may not be able to justify metal recovery because it does not generate enough waste to offer significant savings. This limitation on small companies is not absolute, however. Therefore, the feasibility of various waste reduction technologies should be determined on a plant specific basis.

1.4 WASTE AUDIT PROTOCOL

A waste reduction audit is an essential starting point for identifying areas where hazardous waste reduction technologies can be incorporated into an existing plant's process. An audit can identify housekeeping problems and operating inefficiencies that cost little to correct. Also, an audit can provide information needed to assess the potential for implementing technologies that require significant capital investments. The critical elements of a successful waste reduction audit program are:

- Management commitment
- Personnel involvement
- Access to background data
- Resources to obtain additional data

A company must overcome certain barriers to perform a successful audit and develop a waste reduction strategy. Not all waste reduction opportunities will be apparent simply by obtaining data. Decisions to implement a waste reduction technology will often require a certain level of risk. Many of the policies developed as part of a waste reduction strategy require modifications to standard operating procedures. Furthermore, the impact of these changes on reducing waste cannot always be determined until they are tested; inevitably some will fail. Therefore, it is essential that management be committed to pursuing waste reduction, be willing to experiment with various ideas, and be prepared to experience failure as well as success.

For a waste audit to be successful, it must be comprehensive. A study of a plant's waste problem requires more than a characterization of the various waste streams. The solution for reducing a particular waste stream often involves modifying material inputs or production procedures. Therefore, an audit must examine raw material usage, production processes and schedules, and waste handling methods together as one system.

The waste reduction audit process can be broken down into several steps, as follows:

- The audit team should prepare for the audit by discussing the plant's current waste generation problems and identifying the production processes that contribute to waste generation.
- The initial survey is performed to assimulate existing background information on the plant's operations. The auditors should compile available data on material flow rates, waste generation rates, and the costs associated with material purchases and waste disposal.
- Background data are analyzed to identify potential waste reduction technologies as well as additional data necessary to evaluate these technologies.
- A comprehensive plant assessment is performed to fill in data gaps and to obtain detailed information such as process bath operation parameters, waste characteristics, and operational procedures. Usually some level of sampling and analyses is necessary.
- The final step in the audit process is the evaluation of waste reduction opportunities. The data obtained during the audit is used to determine the applicability of various waste reduction technologies, and economic information is used to perform cost/benefit analyses on applicable technologies.

The results of an audit do not necessarily result in a definitive plan for addressing all of the plant's waste management problems. Experiments in modifying process parameters or production procedures may continue. The results of the audit, therefore, are used to develop a waste reduction strategy that will be an ongoing effort.

1.5 INDIVIDUAL AUDIT FINDINGS

Data obtained during the three audits provided valuable information on the barriers to waste reduction present in the PC board manufacturing industry as well as information on waste reduction technologies available to the industry. Several waste management characteristics common to the PC board industry were identified and are listed as follows:

- The highest priority for a PC board manufacturing company is meeting its requirements for discharge of treated wastewater to the local POTW. As a result, waste reduction is a lower priority.

- PC board manufacturers are hesitant to implement waste reduction technologies that require modifications to process bath operating parameters and procedures.

- Chemical manufacturers emphasize their research and development on products that are treatable in a plant's industrial waste treatment system. However, they do not emphasize research and development of process chemistries that reduce the volume of waste.

- PC board manufacturers are aware of their hazardous waste generation rates, disposal costs, and waste handling costs but know little about waste generation characteristics such as drag-out rates or rinse system flow rates. This inhibits their ability to implement process modifications intended to reduce waste generation.

CHAPTER 2.0

RECOMMENDATIONS

The objectives of this study were to identify waste reduction opportunities available to the PC board manufacturing industry and to develop an audit protocol that could be used by PC board manufacturers to assess their individual waste reduction opportunities. The results of this study can assist the industry in reducing the volume of hazardous waste generated. Using the information obtained during the study and the results presented in this report, PRC developed the following recommendations:

- The audit protocol contained in Chapter 8.0 and the audit working papers in Appendix A should be made available to the PC board manufacturing industry.

- Training sessions should be held with PC board manufacturers using the audit protocol. These sessions would provide PC board manufacturers with an opportunity to ask questions about waste auditing, which would help overcome their reluctance in performing their own waste audit. Examples could be presented that show how the forms are used during an audit and what type of waste reduction opportunities can be identified.

- Process chemical manufacturers should be encouraged to devote some of their research and development efforts to (1) study the impacts of their process chemistries on hazardous waste generation, (2) assess the impacts that various waste reduction technologies have on their process chemicals, and (3) develop process chemicals that are amenable to various waste reduction technologies.

CHAPTER 3.0

INTRODUCTION

Planning Research Corporation (PRC) prepared this report to present the results of a waste audit study of the printed circuit board industry. The study was performed to identify opportunities for waste reduction in the printed circuit board (PC board) industry and to develop a generic audit protocol that PC board manufacturers could use to assess their specific waste reduction opportunities.

3.1 BACKGROUND

Technologies are now being developed that will enable industries to recover valuable materials from their waste streams and to reduce or eliminate hazardous waste generation. These waste reduction innovations are becoming common to large industrial operations with sufficient capital and staff capable of researching and implementing waste reduction technologies. However, most smaller companies do not have the in-house expertise or capital available to develop these technologies themselves. Developing a model waste audit and then making it available to these industries can effectively transfer information to smaller industrial operations on how to achieve cost benefits by reducing the hazardous wastes they generate.

3.2 PURPOSE OF THE STUDY

California was the first state to ban landfill disposal of certain hazardous wastes. In response to the state's land disposal phase-out mandate, the California Department of Health Services (DHS) is implementing a broad program of hazardous waste reduction. The program's emphasis is on small businesses that are unaware of hazardous waste management issues and lack the expertise to address them. The waste audit study for the printed circuit board (PC board) industry is part of this program.

The objectives of this waste audit study were (1) to obtain information on the current waste management practices and problems that exist within the PC board manufacturing industry, (2) to identify alternative waste reduction options available to PC board manufacturers, and (3) to develop a generic audit protocol that can be used by PC board manufacturers to assess their own specific waste reduction opportunities. The results of the study are presented in this report.

3.3 PROJECT APPROACH

To identify waste reduction opportunities available to PC board manufacturers and to develop the generic audit protocol for the industry, PRC conducted waste audits at three PC board manufacturing plants. PC board manufacturers in the South Bay Area were surveyed and three were chosen primarily on the basis of their interest in the program. The waste auditors then reviewed each company's existing manufacturing processes and waste handling procedures and identified opportunities for waste reduction. Two separate visits to each plant were required to perform the audits.

During the first visit to each plant, the auditors collected background information on production and waste handling operations. This information included such data as process flows, material inputs, waste outputs, production schedules, material costs, and waste disposal costs. These visits included a thorough tour of the plant. Information gathered during the initial visit was reviewed and used to plan the activities of the second visit.

The second visit involved a more detailed plant inspection. The auditors reviewed various production and treatment processes with production personnel. Flow rates for the various rinsing operations were calculated where necessary, and spent chemical bath dump schedules and procedures were discussed. PRC observed and asked questions on operational procedures performed by plant personnel. The treatment processes used at each plant's industrial waste treatment facility were reviewed and treatment chemical feed rates and sludge generation rates were determined.

The results of each waste reduction audit were presented to the company in a written engineering report. The report described the audit process, information that was obtained, and opportunities for hazardous waste reduction identified during the audit. The report also included cost estimates for implementing plant modifications and estimates for reductions in hazardous waste generation and associated cost savings, where applicable.

Information obtained during the three audits was used to develop this waste reduction audit study report. This report is intended to:

- Identify the various waste reduction technologies available to PC board manufacturers
- Present information on the costs associated with implementing some of these technologies
- Describe the limitations and inhibiting factors to waste reduction present in the PC board manufacturing industry
- Provide a generic audit protocol that can be used by PC board manufacturers to assess their own waste reduction opportunities

3.4 WASTE GENERATING CHARACTERISTICS OF THE PC BOARD INDUSTRY

Printed circuit board manufacturing requires the use of process chemicals to clean, electroplate, electroless plate, and etch copper/fiberglass base material. This material is used to develop circuit configurations and mounting holes. These processes generate hazardous wastes, the most common sources of which are rinse water effluent, spent process baths, and equipment cleaning chemicals. Table 3-1 lists several types of hazardous wastes that are typically generated by a printed circuit board manufacturer. Usually, rinse water effluent and many of the spent process bath solutions are treated on-site before being discharged to a local publicly owned treatment works (POTW). These on-site treatment systems often produce a heavy metal sludge that is hauled off-site for either disposal or metal reclamation. Some spent process baths and equipment clean-out solutions can also be containerized for off-site treatment or disposal.

Several process operation and production management techniques are available to the PC board manufacturing industry to reduce generation of hazardous waste. Many of these techniques have been developed by other industries, such as the metal plating industry, and can be applied to the PC board industry because production processes and waste characteristics are similar.

TABLE 3-1

COMMON HAZARDOUS WASTES GENERATED BY PRINTED CIRCUIT BOARD MANUFACTURERS

- Industrial waste treatment sludge - Sludge containing metals such as copper, chromium, lead, and tin.

- Spent process bath chemicals - Contaminated or spent electroplating baths such as acid/copper and tin/lead and other process baths such as photoresist stripper, reflow oil, and etchants.

- Equipment cleaning materials - Nitric acid and fluoroboric acid containing metals such as copper, tin, and lead.

- Copper crystals - Copper sulfate crystals generated in process baths such as peroxide/sulfuric etchant baths.

3.5 LIMITATIONS TO WASTE REDUCTION

It is important to identify limitations to waste reduction that PC board manufacturers face as well as to identify waste reduction opportunities. An understanding of these limiting factors is necessary so that they can be overcome.

Although many waste reduction technologies applicable to the PC board industry require little capital investment, several resource recovery, recycling, and alternative treatment technologies require significant capital investments. For example, on-site process chemical or metal recovery systems (such as ion exchange or electrolytic recovery) can cost over $20,000 to purchase and install. Often, the savings to a small company does not warrant the cost of the system. Nevertheless, many housekeeping and process modifications can be implemented for little or no capital investment. These include improving the efficiency of the rinse systems and reducing drag-out. Regardless of plant size, the main reason companies do not implement waste reduction techniques is that management lacks a commitment to pursuing waste reduction.

Implementing a waste reduction program requires commitment of management and a willingness to test new ideas. Many of the waste reduction strategies require modifications to standard operating procedures. Furthermore, how well these changes will reduce waste cannot always be determined until they are tested; inevitably some will fail. These failures can cost the company time and money, which may hinder future efforts at waste reduction. It is essential that management be committed to pursuing waste reduction, be willing to experiment with various ideas, and be prepared to experience failure as well as success.

People involved in implementing waste reduction programs have noted several inhibiting factors. These barriers must be identified by those attempting to develop a waste reduction strategy for their company so that resistance can be recognized and overcome. Several common barriers to waste reduction are as follows:

- Lack of information about available waste reduction techniques and the benefits that can be achieved.
- Concerns for upsetting product quality.
- The "If it ain't broke - don't fix it" attitude.
- A reluctance to develop innovative ideas because of the fear of failure.
- The attitude that a new technology will not succeed because it is outside the company's normal range of expertise.

CHAPTER 4.0

SOURCE REDUCTION

Source reduction technologies are designed to reduce the volume of wastes initially generated by a plant. For the printed circuit board industry, these technologies include reducing the volume of wastewater that requires treatment and extending the life of chemical process baths. Although some of these methods directly reduce the volume of hazardous waste generated, most indirectly reduce this volume by reducing the volume of industrial waste that requires treatment. Therefore, the volume of hazardous waste sludge generated during the treatment of industrial waste is reduced.

Source reduction is usually the least expensive approach to minimizing waste. Many of the source reduction options available to PC board manufacturers only require housekeeping changes or minor in-plant process modifications. The following six categories of source reduction were identified for inclusion in the study:

- Product Reformulation
- Material Substitution
- Plant Modernization
- Process Redesign
- Process Automation
- Improved Operating Practices and Housekeeping

Three of the categories, Material Substitution; Process Automation; and Improved Operating Practices and Housekeeping, are discussed in Sections 4.1, 4.2, and 4.3 respectively. The remaining three categories either do not present significant waste reduction opportunities to PC board manufacturers or, are considered broad categories that include waste reduction technologies described throughout this report. These three categories are briefly discussed in the following paragraphs.

Product reformulation has only limited application to the PC board manufacturing industry. The general design of a printed circuit board is the same whether it is to be used in a computer or a household appliance. A printed circuit board consists of an insulating material on which conducting material is placed. The insulating material is usually fiberglass or phenolic plastic. Conducting materials, which are metals such as copper, are layered onto the fiberglass or plastic board.

The primary sources of hazardous waste are the processes used to layer the conducting material onto the insulating material. Since the metals used to produce circuit configuration on the board are chosen for conductive properties, product reformulation by substitution of these metals is unlikely. Process modification, however, is feasible and is discussed throughout this report.

Plant modernization and process redesign technologies available to the PC board industry can be classified into several other waste reduction categories. Many of the source reduction, recycling technologies and alternative treatment technologies discussed in this report may be considered plant modernization or process redesign. Therefore, these two categories are addressed throughout Chapters 4.0, 5.0 and 6.0 when describing various waste reduction technologies.

4.1 MATERIAL SUBSTITUTION

Opportunities to reduce waste by substituting materials are available to the PC board manufacturing industry. Most of these options involve modifying the chemistry of the various process baths. Since the chemistry requirements of each plant are different, these options can only be described in general terms. Some are discussed in the Jacobs/USEPA report.

4.2 PROCESS AUTOMATION

Little potential exists for a PC board manufacturer to reduce waste by automating its manufacturing process. This is especially true for the small- to medium-sized companies that run their production lines manually with only a few operators. A waste reduction technique that uses rinse water flow controls may, however, be considered an automated operation. This technique is discussed in the Jacobs/USEPA Supplement under improved rinse efficiency.

One area where process automation could contribute to waste reduction is in control of drag-out. An automated rack line could be set to remove work piece racks at a slow rate and allow adequate drain time before the rinse cycle. However, such a system is not likely to be financially feasible because most process lines do not run continuously. Such an automated unit would usually not be in operation and, therefore, would not replace manual labor to the level necessary to warrant its consideration. Applicable drag-out reduction techniques are discussed in Section 4.3.2.

4.3 IMPROVED OPERATING PRACTICES AND HOUSEKEEPING

Source reduction options that involve improving operating efficiency and housekeeping provide the most opportunities for waste reduction in the PC board manufacturing industry. Technologies designed to reduce the volume of rinse water used or to recover drag-out are available to the industry. Many of these options require little, if any, capital investments.

The most significant source of hazardous waste in PC board manufacturing is the treatment of wastewaters, which produces a hazardous waste sludge. Most wastewater is generated by rinsing operations. By improving the efficiency of the rinse system and reducing the volume of process chemicals carried away in the rinse water (drag-out), hazardous waste generation can be reduced. Another waste source that can be reduced by improving operating practices is spent cleaning solutions generated during equipment cleaning operations. These waste reduction technologies are discussed in the Jacobs/USEPA Supplement.

4.3.1 Improved Rinse Efficiency

This is discussed in more detail in the Jacobs/USEPA report.

4.3.2 Drag-Out Reduction

Process chemical loss due to drag-out is the most significant source of chemicals entering wastewater. Treatment of this wastewater is the major source of hazardous waste because of the resulting sludge. Therefore, the volume of sludge generated is proportional to the level of contamination in the spent rinse water (Couture, 1984). Figure 4-1 illustrates the relationship between metal concentration and sludge volume. The graph shows the percentage of sludge per volume of water treated at various levels of heavy metal concentration of the wastewater. The graph shows that 1000 gallons of wastewater with a heavy metal concentration of 100 mg/l will produce approximately 90 gallons of sludge. If the same volume of wastewater had a metals concentration of 500 mg/l, approximately 280 gallons of sludge would be generated. The graph is based on data obtained from the metal plating industry. Although the actual values may differ, the impact of metal concentration on wastewater sludge volume should be similar for the PC board manufacturing industry.

Table 4-1 summarizes the techniques available to the PC board manufacturing industry to reduce process chemical drag-out. These techniques are described in the Jacobs/USEPA Supplement.

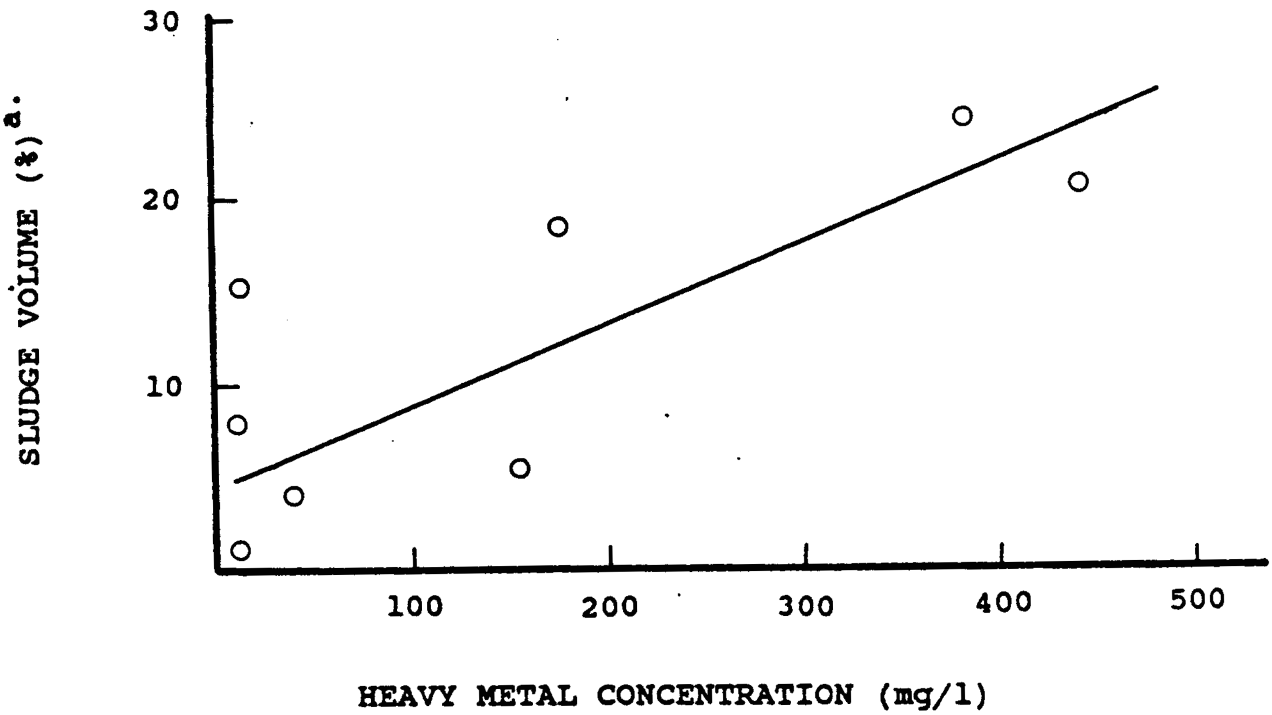

FIGURE 4-1 - SLUDGE VOLUME GENERATION

a. Volume of sludge per volume of wastewater treated after 1 hour of settling. Treatment consists of lime neutralization.

(Source: U.S. EPA, Environmental Pollution Control Alternatives: Sludge Handling, Dewatering, and Disposal Alternatives for the Metal Finishing Industry, October, 1982.)

TABLE 4-1

DRAG-OUT LOSS REDUCTION TECHNIQUES

1. Minimize bath chemical concentrations by maintaining chemistry at the lower end of operating range.

4. Maximize bath operating temperature to lower the solution viscosity.

3. Use wetting agents in the process bath to reduce the surface tension of the solution.

4. Maintain racking orientations to achieve best drainage.

5. Withdraw boards at slower rates and allow sufficient solution drainage before rinsing.

6. Utilize drainage boards between process and rinse tanks to route drippage back to process tanks.

7. Use drag-out tanks to recover process chemicals for reuse in process baths.

(Couture, 1984)

CHAPTER 5.0

RECYCLING AND RESOURCE RECOVERY

5.1 WASTE MATERIAL REUSE

Figure 5-1 is a flow diagram illustrating the use of rinse water recycling for an alkaline cleaning, mild acid etch, and acid cleaning line. If each of the three rinse tanks are operated at the same flow rate, total water use could be reduced by 67 percent.

Just as rinse water solutions can be reused, some spent chemical process baths can also be used for other purposes. The most common use for a spent process bath is to use acid or alkaline cleaners for pH adjustment during treatment of the industrial waste stream.

5.2 MATERIAL RECYCLING

Opportunities for material recycling include process bath regeneration, process chemical and metal recovery and rinse water recovery. Material recycling usually involves a process step that produces a residual. However, the recycling process can significantly reduce the volume of the waste material or can render the residual nonhazardous. For example, recovery of process chemicals from rinse water effluent can produce a waste stream that can either be reused for rinse operations or neutralized prior to discharge to the sanitary sewer.

5.2.1 Process Bath Regeneration

PRC identified two types of process baths that can be regenerated by PC board manufacturers. These are strong and mild acid etchants and alkaline photoresist stripper. Spent process bath solutions can be regenerated to recycle valuable etchants. PC board manufacturing requires the use of mild and strong etchants. These etchants are considered spent when the copper concentration reaches a level at which etching efficiency is inadequate. The

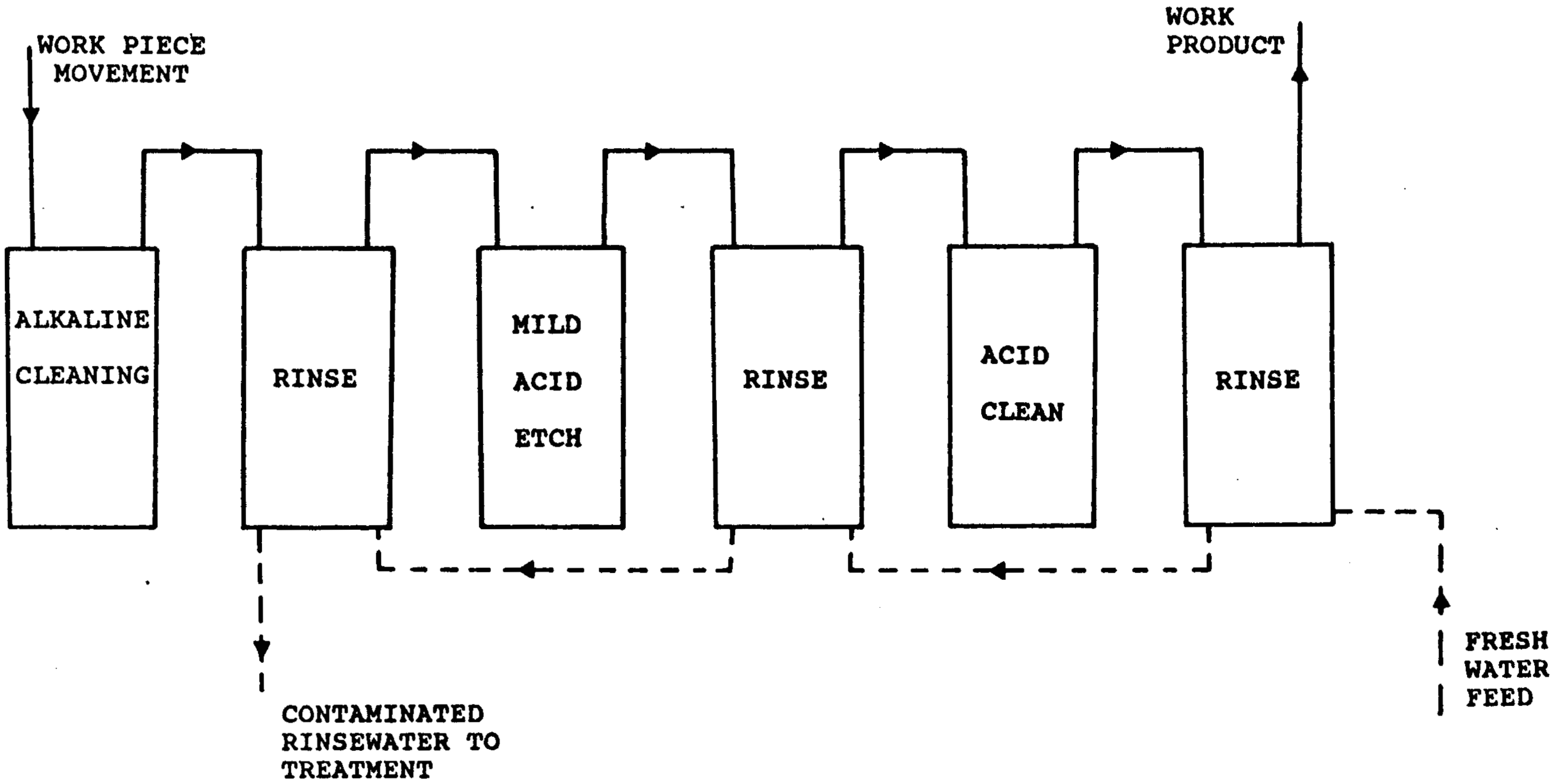

FIGURE 5-1 - MULTIPLE REUSE OF RINSEWATER

Jacobs/USEPA Supplement has two examples describing how these etchants can be recycled.

Another process bath that is commonly containerized for off-site disposal is spent photoresist stripper. Stripper is used to remove photoresist material from the board. This photoresist is a polymer material that remains in the stripper tank in small flakes that slowly settle to the bottom. These flakes become suspended in the stripper solution when agitated. Therefore, when the sludge formed at the bottom of the stripper tank builds up, the flakes begin to adhere to circuit boards when they are cleaned in the stripper tank. The stripper solution is considered spent when this occurs.

Two options are available to reduce the generation of this stripper waste. First, if the photoresist stripper line is set up as a multistage process, the stripper would not have to be changed as often. The suspended polymer flakes causing problems in the first tank would be removed in the second tank. Therefore, the stripper waste in the first tank would not need to be disposed of as frequently.

The second technique would be to decant and filter the stripper solution out of the tank into a clean tank. This is feasible because the stripper usually becomes spent as a result of the residue buildup long before it becomes spent as a result of a decrease in chemical strength.

5.2.2 Metal and Process Bath Recovery

The waste reduction and economic savings actually achieved through metal recovery will depend on the individual manufacturing plant. Factors that will determine whether metal recovery is economically justifiable include the volume of waste that contains metals, the concentrations of those metals in the waste, and the potential to recirculate some of the metal salts. Many systems may not be economically feasible for small PC board manufacturers because the savings from recovering process chemicals may not be great enough to achieve an acceptable payback on their investment. Some of these systems are described in the Jacobs/USEPA Supplement.

5.2.3 Rinse Water Recovery

In addition to reusing rinse water effluent for rinse water influent, PC board manufacturers can recycle rinse waters by treatment. Several of the process bath recovery technologies discussed in the Jacobs/USEPA Supplement can be used strictly as rinse water recycling systems. RO and IE units can be installed to treat the entire rinse water waste stream. Rinse water recovery has an advantage over process bath recovery because the recycling unit can treat all the waste streams together instead of treating only a specific waste stream. Since process chemicals are not recovered, the various waste streams need not be segregated.

The use of an RO or IE unit to recycle all rinse water waste streams may require additional treatment. Several of the waste streams contain organics. Therefore, a carbon filtration system may also be necessary to remove the organics before the rinse water can be reused.

5.3 MATERIAL SUBSTITUTION

Material substitution is discussed earlier in Section 4.1.

Another material substitution option that may be available to a PC board manufacturer is the use of recyclable materials. Chemical manufacturers and suppliers, aware of their clients' increased concern for industrial waste treatment and disposal, provide many process chemicals that can be recycled or returned to the supplier. For example, some suppliers of reflow oil, which is used to enhance the formation of a smooth film of solder on the circuit board, provide a product that can be returned for recycling. Non recyclable reflow oils are typically handled as a hazardous waste. PC board manufacturers should be aware of current process chemical technologies by participating in industry trade groups and maintaining contact with chemical manufacturers.

CHAPTER 6.0

TREATMENT ALTERNATIVES

Waste reduction treatment alternatives include the pretreatment of process water and the treatment of waste streams to reduce their volume or hazard. Source segregation and treatment process modifications are also included in the discussion of treatment alternatives. Opportunities to reduce waste by implementing treatment alternatives that are available to the PC board manufacturing industry include pretreating process water, using alternative waste treatment chemicals, segregating waste streams, dewatering sludge, and using alternative wastewater treatment systems such as ion exchange. This section describes the various treatment alternatives available to PC board manufacturers. Additional details are in the Jacobs/USEPA Supplement.

6.1 WATER SUPPLY TREATMENT

Natural minerals in water used for production processes can contribute to the volume of waste generated. During treatment of wastewater, these minerals will precipitate as carbonates and phosphates and will contribute to the volume of sludge (EPA, 1982b). How much these increase sludge volume will depend on the hardness of the water in the area. In addition to the direct effect on sludge volume, the presence of these minerals in the water may reduce rinse water efficiency. Therefore, rinse systems may require more water than would be necessary if the water were demineralized prior to use.

Deionized water systems can be installed to treat water prior to use in production processes. It is difficult to estimate the level of sludge reduction or water use reduction that can be achieved, however. It may be possible to evaluate the effect of using deionized water by determining the hardness of the incoming tap water and estimating the level of removal that will occur in the treatment system.

6.2 ALTERNATIVE WASTE TREATMENT CHEMICALS

6.3 WASTE SEGREGATION

Segregating waste streams can effectively improve the efficiency of a waste treatment system. This is discussed in the Jacobs/USEPA Supplement.

6.4 SLUDGE DEWATERING

Increasing the solids content of industrial waste sludge can significantly reduce the volume of sludge requiring off-site transport and disposal. Typically, the sludge removed from a clarifier is approximately 3 percent solids by weight. One plant visited by PRC used a bag filtration process to increase the solids content of their sludge to 10 to 12 percent. In this process, sludge from the clarifier flows by gravity into a series of fine meshed bags and water is allowed to drain out of the sludge. Additional increases in solids content will generally require some form of mechanical dewatering to significantly reduce sludge volume. For example, increasing solids content from 3 percent to 35 percent can achieve an 8:1 reduction in sludge volume (Basanese, 1987). Figure 6-1 shows the reductions in sludge volume that can be achieved by increasing the percent solids of the sludge.

Several techniques are available for dewatering sludge. Generally, these systems are reserved for plants that generate more than 200 to 400 gallons of sludge each month, which is typical of a small PC board manufacturing plant. However, mechanical equipment designed for lower volume generators is becoming more common. These dewatering systems include filter presses and sludge drying units.

6.5 ALTERNATIVE WASTEWATER TREATMENT-ION EXCHANGE

Ion exchange (IE) is discussed in the Jacobs/USEPA Supplement as a technology that can be used to recover process bath chemicals and recycle rinse waters. IE can also be used as a wastewater treatment alternative. Unlike IE systems used for process chemical recovery, IE systems used for wastewater treatment can treat the entire waste stream. Hazardous waste volume can still be significantly reduced because the IE system eliminates the generation of heavy metal sludge. One PC board manufacturer audited

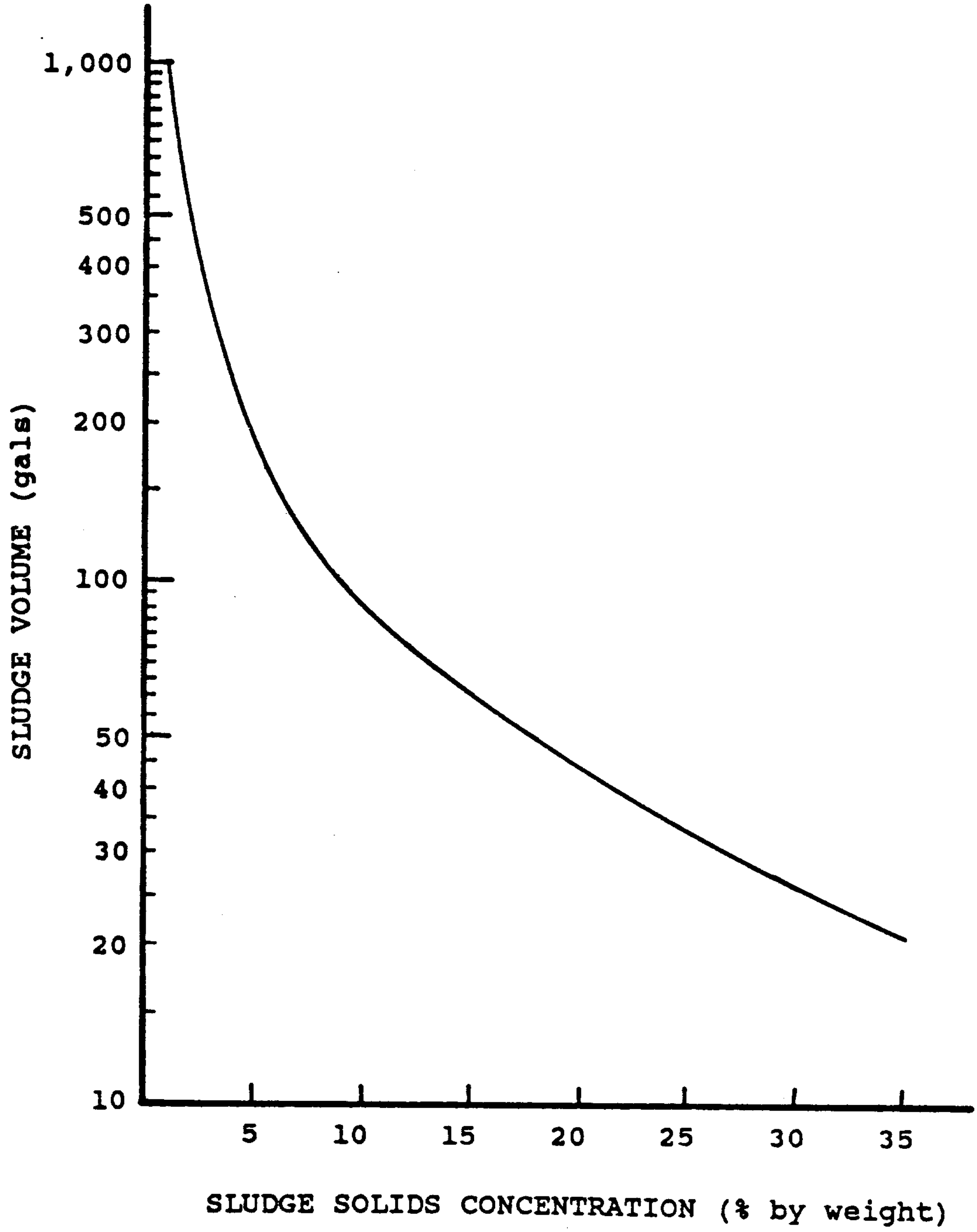

FIGURE 6-1 - SLUDGE VOLUME VS SLUDGE SOLIDS CONCENTRATION during the study was able to eliminate all sludge generation by installing an IE unit to replace the conventional precipitation/clarification treatment system. The company now generates approximately 50 percent less hazardous waste from its industrial waste treatment system. The hazardous waste generated by the IE unit is in the form of spent ion resin. This IE system has also allowed the company to successfully comply with local pretreatment regulations. The previous system had been producing effluent that did not meet the required pretreatment standards. Figure 6-2 is an illustration of a typical IE system installed to treat rinse water wastes prior to discharge to the local POTW.

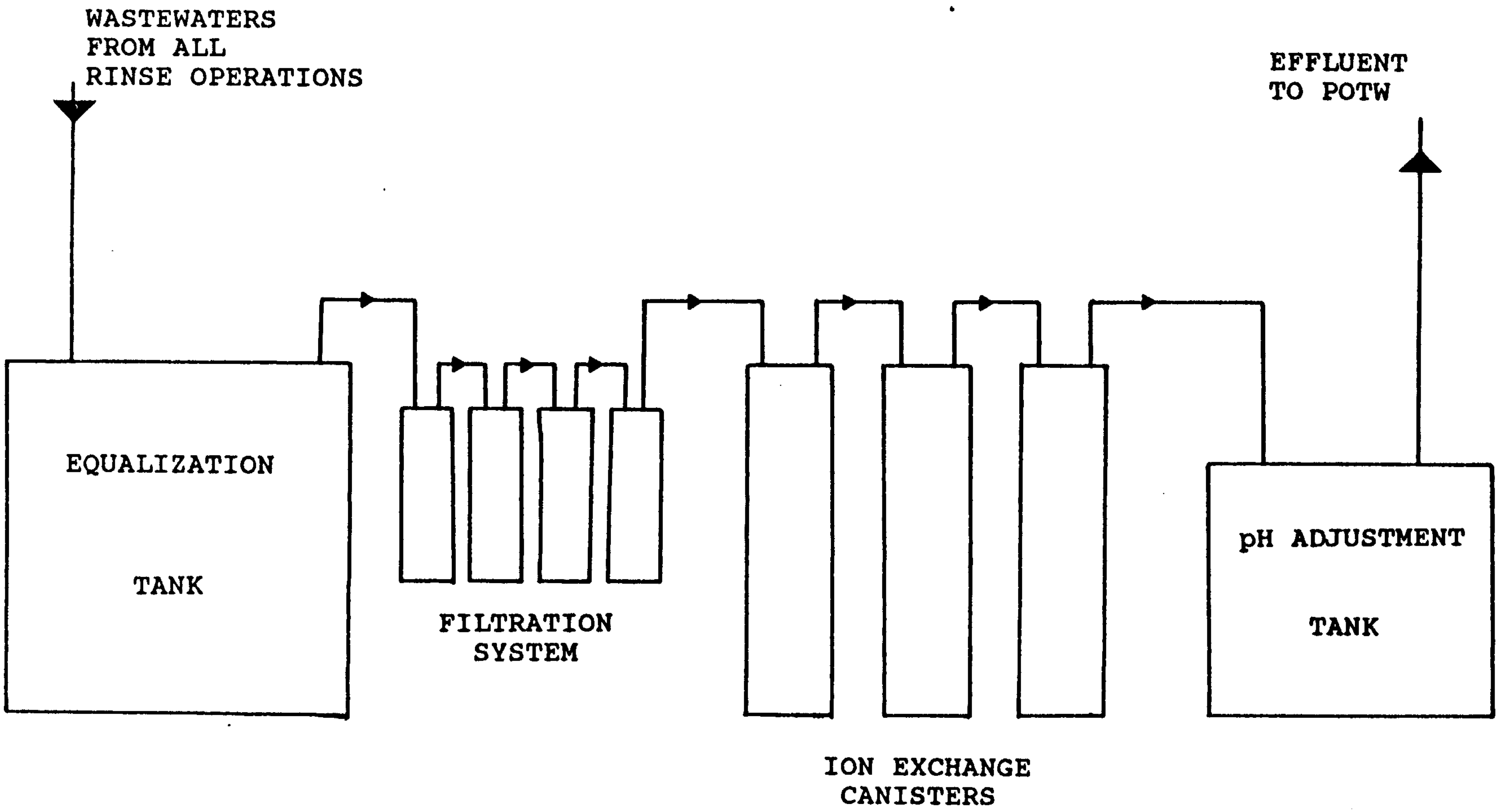

FIGURE 6-2 - ION EXCHANGE WASTEWATER TREATMENT

CHAPTER 7.0

ECONOMICS

The cost associated with various waste reduction technologies is key to determining the feasibility of incorporating a waste reduction technique into a company's operations. Cost considerations include capital investments in equipment and installation, possible production down-time during installation, costs for operation and maintenance and potential impacts on product quality and production time. These costs must be compared to potential benefits. The benefits in this case include reduced waste handling and raw material costs. Other benefits, including reductions in potential liabilities associated with generating, storing, and disposing of hazardous wastes, are virtually impossible to quantify.

Cost/benefit evaluations for implementing various waste reduction techniques at a specific plant will vary with plant size, production rates, raw material usage, and waste generation characteristics and volumes. Although cost estimates for many of the waste reduction methods described in this report can be developed, savings, in terms of reduced material and waste handling costs, are plant specific.

This section contains information that can be used to assist in evaluating the economics associated with various waste reduction technologies available to the PC board manufacturing industry. The costs associated with many of the waste reduction technologies are presented, and where possible, examples of the potential savings these technologies can provide are given.

7.1 SOURCE REDUCTION

Source reduction techniques available to PC board manufacturers are generally the most economically feasible. Many of these technologies only require proper training of production personnel or minor modifications to processes. Several technologies, however, such as multi-stage rinsing and flow regulators do require considerable capital investment.

7.1.1 Material Substitution

Material substitution techniques to reduce the source of waste include the use of non-chelator chemistries in place of process chemistries that contain chelators. A variety of process chemicals are available that contain low or non-chelated chemicals for plating, acid and alkaline cleaning, and various etching processes. These types of process chemicals cost slightly more than chelated chemicals but, the difference is too small to be considered a deciding factor when choosing between the two types (Foggia, 1987). The main reason why most PC board manufacturers do not use non-chelate process chemistries is because of the increased maintenance costs associated with non-chelated process baths.

Non-chelated process baths usually require continuous filtration during the life of the bath, which requires the installation of a filter system to remove the solids that will form in the bath. The costs of these filter systems will range from approximately $400 to $1,000 for each tank using a non-chelated process chemistry. These systems generally have a 1 to 5 micron filter with a control pump that can filter the tanks contents once or twice each hour (Foggia, 1987). In addition to the purchase and setup costs, filter replacement and maintenance costs will be incurred.

Expected savings of using non-chelated process chemicals include reduced treatment costs and sludge handling costs. Another important advantage to using these chemicals is that metals removal efficiency is usually improved. Therefore, the treated effluent is more likely to meet POTW industrial waste effluent discharge requirements.

Although the specific savings associated with the use of non-chelated chemistries can not be quantified, the following example illustrates the potential for savings. One PC board manufacturer visited during the audit study used ferrous sulfate to break down chelators prior to metals precipitation. The iron present in the resultant sludge contributed approximately 32 percent of the total dry weight of the sludge. Therefore, the elimination of the ferrous sulfate from the treatment system would reduce sludge volume by approximately 30 percent, assuming that the solids concentration remains the same.

7.1.2 Rinse Efficiency

Rinse water reduction techniques cover a wide range of costs. Use of multistage, counter-current rinse systems are generally not applicable to small companies because of cost and floor space limitations. Other options such as simple rinse water flow rate reduction or air agitation are less expensive and may be feasible for smaller shops. Table 7-1 presents the costs associated with purchasing several types of rinse efficiency equipment.

A counter-current triple-rinse system requires the installation of two additional rinse tanks and the associated piping. The cost of such a system can be about $1,000 (Terran, 1987). Automated controls, such as pH meters, to control rinse water flow can effectively reduce rinse water waste generation. A pH meter equiped with the necessary control valves and solenoids could cost approximately $700 per tank (Ryan, 1987).

Air spargers could be installed in existing rinse tanks for a modest cost. Assuming the plant has a sufficient quantity of compressed air on-site that is readily available, the costs of installing air spargers would be $100 to $125 per tank for a 50 gallon capacity tank.

PC board manufacturers can also reduce their rinse water usage without spending large amounts of money. By manually agitating work pieces in the rinse water and allowing increased rinse water contact time, a plant can reduce the rate of rinse water flow without significantly impacting rinse efficiency. Therefore, water use can be reduced without a significant investment. The only necessary requirements are purchasing flow restrictors and training personnel.

The savings associated with reducing rinse water usage are primarily from reduced water and sewer fees. By increasing rinse efficiency, a process line can reduce waste-water flows by as much as 90 percent (Watson, 1973). However, most small or medium PC board manufacturing plants would not achieve such large reductions. Improved rinse efficiency should also reduce sludge generation, although this is difficult to quantify before implementing a system.

TABLE 7-1

CAPITAL COST FOR RINSE EFFICIENCY EQUIPMENT

Equipment	Cost	Description
Rinse/Drip Tank	$ 350.00/ tank	50 gallon polyethelene tank
Air Agitator	$ 50.00/ tank	Air Spargers, Assumes plant has sufficient compressed air readily available.
pH/Conductivity Meter	$ 700.00/ tank	Sensors, solenoids and valves
Labor	$ 57.00/ per hr.	Installation of air spargers requires approximately 2 hours per tank. A three-stage counter-current rinse system requires approximately 5 to 8 hours to install.

(Terran, 1987)

The savings that can be achieved by instituting a rinse water reduction program is illustrated in the following example. If a company spends approximately $400 each month for water and sewer fees, a modest reduction in rinse water usage of 10 percent can, theoretically, save the company $40 each month. If a two year payback on investment is acceptable, the company could justify spending approximately $1,000 to reduce its rinse water usage. This could be spent on airspargers and flow restrictors. If more significant reductions are achievable (perhaps 50 percent) a company could justify more advanced technologies such as pH meters or counter-current rinse systems. Potential savings in sludge disposal costs and treatment chemical use associated with reducing the volume of waste water requiring treatment would also contribute to the payback on investment.

7.1.3 Drag-Out Reduction

Most of the drag-out reduction techniques discussed in Section 4.3.2 do not require any capital investment. These techniques do, however, require training of personnel. For example, removing work piece racks at a slower rate to reduce drag-out or allowing the rack to drain over the process tank for a longer period of time requires a conciencious operator. These procedures should not significantly affect production.

Savings that can be experienced by using drag-out reduction techniques include reductions in process chemical purchases, water and sewer use fees, and sludge handling costs.

A few drag-out reduction techniques do require capital expenditures. Rails installed above process tanks can be used to hang work piece racks and allow drag-out to drain back into the process tank. It should not cost more than a few hundred dollars to equip all process tanks with these rails if PVC piping is used and installation is performed by plant personnel. Use of a drag-out tank will require the purchase of an additional tank. This could cost approximately $350. Since these tanks are not used as flow-through tanks, they could be setup without any plumbing. Typically drag-out solutions are manually dumped or added to the process bath.

Generally, the use of a drag-out tank can reduce both rinse water usage and chemical losses by 50 percent or more (EPA, 1982a). Assuming that a chemical bath processes 3,000 square feet of board each month, the total volume of drag-out loss each month would be 12 gallons, with a drag-out rate of 15 ml/square foot of board. If the rinse system following the process bath operates at a flow rate of 10 gpm, for a total of 2 hours each day, water usage would be 24,000 gallons per month based on 20 work days per month. A 50 percent reduction in chemical loss and water usage achieved by installing a drag-out tank would reduce chemical losses by 6 gallons per month and water usage by 12,000 gallons. If water and sewer fees are each $0.50 per 100 cubic feet, a savings of 16 dollars per month could be realized. Chemical savings would depend on the type of process chemical and the amount of drag-out that could be returned to the process tank. There would also be a savings in treatment chemicals realized by reducing rinse water effluent. If the company spends approximately $1,000 each month on chemicals to treat 200,000 gallons of water, reducing wastewater generation by 12,000 could reduce treatment chemical usage by $60 each month.

7.1.4 Equipment Cleaning Solution Reduction

A common hazardous waste stream generated by PC board manufacturers is waste nitric acid generated from the cleaning of electroplating work piece racks. Typically, racks are placed in a nitric acid bath to clean-off the plated copper. When the copper content in the bath gets too high to effectively clean the racks, the nitric acid is containerized for disposal. Use of a cascade cleaning system (the Jacobs/USEPA Supplement) can significantly reduce nitric acid waste generation. The costs associated with setting up such a system are the cost of additional tanks and the labor costs for their installation. The costs for setting up a cascade cleaning line would be approximately $350 per tank. Labor costs of $55 an hour for 4 hours would be $220. The savings associated with a cascade plating rack cleaning line include reduced costs for nitric acid purchases and waste acid handling.

PRC visited one small PC board manufacturer who operates a five tank plating rack cleaning line. The company generates approximately 15 gallons of waste nitric acid in 6 months. By comparison, another small company that uses a single tank for cleaning racks generates approximately 60 gallons each month. If this second company could reduce that volume by 50 percent by installing a multistage cleaning line, it could realize a significant savings in waste handling and material purchasing cost. Assuming that waste disposal for the spent nitric is $50 per 55-gallon drum, waste disposal costs could be reduced by $167 each 6 months. Since the cost of technical grade nitric acid is approximately $3.50 per gallon, acid purchases could be reduced by $630 each 6 months. Total savings would be $1600 each year. The total cost of a five tank cleaning line would be $1620 which is the cost for the purchase and installation of four additional tanks.

7.2 RECYCLING AND RESOURCE RECOVERY

Recycling and resource recovery costs range from making minor investments for plumbing modifications to purchasing expensive systems for chemical recovery units. Waste reduction alternatives include direct reuse of waste streams and recycling of chemicals.

7.2.1 Waste Material Reuse

A waste material reuse option common among PC board manufacturers is the recycling of rinse waters. The primary costs associated with rinse water recycling is replumbing the rinse system to allow for reuse of rinse water effluent. Depending on the design of the rinse water reuse system, storage tanks and pumps may also be needed.

Implementing a system to reuse rinse water effluent from one rinse system for feed water into another rinse system costs approximately $1,000. This includes $500 for contractor labor for 1 day and $500 for materials that includes piping materials and a three-quarter horsepower pump, which would be adequate for a typical rinse system. Assuming that both rinse systems are in the same process line and operate at the same flow rate, no storage tank capacity would be necessary.

The savings associated with reusing rinse water include water and sewer fees, treatment chemicals, and sludge handling. If each individual rinse system used 24,000 gallons of water each month, the reuse of rinse water from one rinse system could reduce water usage by 24,000 gallons each month. This equates to a savings of $32 per month assuming water and sewer fees both equal $0.50 per 100 cubic feet. Savings in treatment chemicals would be approximately $120 each month assuming the company spends $1,000 each month to treat 200,000 gallons of wastewater.

Other material reuse options, such as using spent acid or alkaline cleaners as neutralizing chemicals in the waste treatment system, can be implemented at practically no cost. The only fees associated with using spent process baths for other purposes would be the purchase of storage containers for the material.

7.2.2 Material Recycling

Material recycling technologies range from simple decantation systems for recovering photoresist stripper (see Section 5.2.1) to advanced recovery units such as reverse osmosis and ion exchange (see Section 5.2.2). The process bath regeneration techniques discussed in Section 5.2.1 generally require little capital investment. The chemical recovery units described in Section 5.2.2 can cost tens of thousands of dollars to implement.

The costs associated with implementing a chemical recovery technology depends on a number of variables: the size of the unit, the space available, equipment rearrangement, production down time, and the specific application. Table 7-2 contains cost data for several chemical recovery units. All of the examples shown in Table 7-2 are from electroplating plants. Although the specific materials recovered may be different for a PC board manufacturing plant, the basic technology is transferrable between these two industries. Although, the equipment costs will be representative of what a PC board manufacturer would need to spend, the annual savings are dependent on the wastewater metal concentrations and volume of wastewater treated by the recovery systems.

One limiting factor for a small PC board manufacturing company is the volume and chemical concentration of its various rinse water effluents. The examples in Table 7-2 are all designed to recover a specific material from a single waste generating source (for example, nickel salts from a nickel plating line). To achieve savings in chemicals and sludge handling that will create a justifiable payback, the waste stream must be fairly concentrated and continuous. For example the nickel salt concentration of the effluent rinse water was 3000 mg/l and had a flow rate of

TABLE 7-2

MATERIAL RECOVERY TECHNOLOGY COSTS

Technology	Materials Recovered	Equipment Costs[a]
Evaporation Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$47,000
Reverse Osmosis Unit: Capacity of approximately 100 gph.	Nickel salt plating chemicals	$27,000
Ion Exchange Unit: Capacity of approximately 20 gph.	Rinse water Chromic acid	$38,000
Electrolytic Unit: Capacity of approximately 15 gph.	Rinse water Copper	$25,000

a. Equipment costs include equipment purchase, installation, and materials.

Source: (United States Environmental Protection Agency, "Environmental Pollution Control Alternatives - Reducing Water Pollution Control costs in the Electroplating Industry," September 1987.)

100 gph. These types of parameters are generally not found in small PC board manufacturing plants. However, each company should evaluate its own conditions to determining the feasibility of material recovery. The information necessary to determine the feasibility includes waste stream generation rates and chemical concentrations, and the value of materials to be recovered.

7.3 TREATMENT ALTERNATIVES

Although treatment alternatives usually produce a residual hazardous waste, many of them can be used to reduce the amount of hazardous waste generated. This can lead to a reduction in the associated costs for waste handling and disposal. For the purpose of this study, treatment alternatives include process water pretreatment, use of alternative chemicals, waste segregation, and sludge dewatering.

7.3.1 Water Supply Treatment

Deionizing the water used in the various rinse operations can reduce waste generation in two ways. First the deionized water improves rinsing. This may contribute to reducing the volume of rinse water used. Second, prior treatment of the rinse water will remove many of the natural contaminants that can find their way into the industrial waste sludge after the wastewater is treated.

The treatment cost to deionize process water depends on the condition of the water supplied to the plant. The cost is dependent on the concentration of total dissolved solids (TDS) in the water (Prothro, 1987). For example, in the Santa Clara Valley a plant supplied with surface water will spend approximately 2 cents per gallon to pretreat process water. A plant supplied with ground water will probably spend closer to 4 cents per gallon. A typical deionizing system, that includes two 14 inch mixed bed deionizers, costs approximately $2,000 for equipment and installation and will treat up to 5,000 gallons a day (Prothro, 1987).

It appears that deionization of the water supply for all process waters is generally not cost effective. For example, a company that currently uses fresh water at the rate of 5,000 gallons per day may realize a 20 percent reduction in fresh water usage through reduced rinse rates if the fresh water were pretreated in a deionizer. The cost of treating the 4,000 gpd the company would now use would be over $1,600/month, assuming a unit cost of $0.02 per gallon and a 5 day work week. After giving consideration to the savings in water and sewer fees ($0.05 per 100 cubic feet for each, water and sewer) and the reduced wastewater treatment costs (20 percent of approximately $1,000 monthly), a company would need to achieve a reduction in sludge disposal costs of approximately $1,475 just to offset the additional treatment costs of the deionizing system. A typical plant of this size is probably currently spending only $200 to $400 per month for sludge disposal. Therefore, a savings of nearly $1,500/month is not possible.

7.3.2 Alternative Waste Treatment Chemicals

The cost associated with using alternative treatment chemicals depends on the plant. The characteristics of the plant's waste stream will dictate the type and amount of chemicals used and the relationship between treatment chemical use and sludge generation. Therefore, it is difficult to provide representative costs and benefits associated with the use of alternative chemicals.

7.3.3 Waste Segregation

The level of redesign and process retrofitting involved with segregating wastes is highly dependent on the plant layout, the process, and the waste streams being segregated. For the purpose of this report we considered waste segregation, rerouting a waste stream and providing a storage facility for the segregated material. This type of segregation could be useful for holding waste streams for batch treatment or for recovering materials from the segregated waste stream.

The level of effort necessary to segregate portions of a waste stream can vary from simple rerouting of waste lines to construction of storage areas with holding tanks. Costs for implementing these modifications range from a few thousand dollars to hundreds of thousands of dollars. The following examples illustrate two possible waste segregation system costs.

A simple form of segregation is to prevent a side stream from entering the main waste stream by redirecting it to a separate storage tank. This could be used to isolate waste containing chelators. Assuming the task only entails installing a 500-gallon storage tank, pumps, gauges, and necessary piping, equipment costs would range between $2,000 and $4,000. In addition, installation costs may be as high as 100 percent of equipment costs.

It may be necessary to construct a larger storage area to contain multiple types of segregated materials. Such a facility could consist of a 25 ft. x 25 ft. concrete containment area, three 1000 gallon storage tanks, and associated piping, pumps, and gauges. Equipment and materials, which includes plumbing, pumps, gauges, and tanks, would cost between $20,000 and $30,000. In addition, installation costs could reach 100 percent of equipment costs. This type of facility would allow segregation of several waste streams for material recovery as well as batch treatment.

7.3.4 Sludge Dewatering

In the past, sludge dewatering technologies were only used by companies that generated large amounts of sludge. A sludge reduction technology report prepared by the EPA in 1982 estimated that if a company spent more than $16,500 annually on sludge handling and disposal, the use of dewatering technologies could be considered economical. Assuming that a PC board manufacturer spends $40 per drum to have its sludge sent to a reclaimer, a company would need to generate over 400 55-gallon drums of sludge each year to warrant consideration of a sludge dewatering unit. Now, however, small filter press dewatering units have been designed for plants that generate approximately 10 to 50 gallons of sludge per week. The costs for these units can still be considered high for a small company, however.

Small filter press units designed to handle from 0.75 gallons to 3.75 gallons of sludge per load cost between $2,800 and $4,900. This assumes that the plant already has a source of compressed air. Larger filter presses that can process from 4.5 to 11.25 gallons of sludge can cost from $7,000 to $9,500. These systems are designed to process two loads per 8 hour shift. Therefore, the smallest unit can handle 7.5 to 37.5 gallons of sludge per 5 day work week, while the larger unit can handle from 45 to 112.5 gallons per week. These units can increase solids content from 1 percent to approximately 35 percent, which represents an 8-to-1 reduction in sludge volume (Basanese, 1987).

Sludge can be further dewatered to 85 to 95 percent solids by using sludge dryers. Sludge dryers with a 1.5-cubic foot capacity, approximately 11.25 gallons, can cost about $30,000. These units would achieve a 3-to-1 reduction in sludge volume if the partially dewatered sludge was approximately 35 percent solids (Basanese, 1987).

A company can develop its own sludge drying equipment for a significantly lower investment. One small PC board manufacturer is planning to convert a small cement mixer into a drying unit by lining the insides with ceramic and placing a heating element in the middle. The unit costs approximately $500 to build. However, since it has not yet been put into operation, its effectiveness could not be determined.

Savings associated with sludge dewatering are achieved in reduced sludge handling costs. For example, a company that sends its sludge to a reclaimer pays $40 per drum. If the company generated 10 drums per month, it could save approximately $350 dollars each month by using a filter press to increase solids content from 1 percent to 35 percent. This assumes an 8-to-1 reduction in sludge volume. A unit large enough to handle 2.5 drums per week would cost approximately $10,000. The pay back on investment would be approximately 2.4 years if labor for operation and maintenance is excluded from the calculation.

7.3.5 Alternative Wastewater Treatment - Ion Exchange

Ion exchange systems can be used to treat the entire wastestream prior to discharge to the POTW. When used for this purpose, the IE units do not recover process chemicals for reuse because all sources of wastewater are mixed prior to treatment. The units can be used to recycle rinse water, however, by utilizing an activated carbon treatment system following IE treatment process. The costs for operating an IE system will depend on the volume and chemical concentrations of the wastewater.

One plant visited by PRC recently installed an IE system to replace it's conventional precipitation/clarifier treatment system. The IE unit is designed for a treatment capacity of 12 to 14 gallons per minute. The unit does not generate any sludge but does generate approximately two 55-gallon drums of spent IE resin each month. The old treatment system generated approximately four to six 55-gallon drums of sludge per month.

The IE system was purchased and installed for approximately $16,000 and required one week of production down time to install. The IE costs $1,000 per month to operate compared to $1,500 per month for the old system. Operating costs include material purchases and waste disposal. The IE requires less labor to maintain according to the company, however, specific labor costs were not available.

According to the company, the IE unit reduces material purchase and waste disposal costs by $400 each month or $4,800 each year. This annual savings would allow for a payback on investment of 3.3 years. The data does not include labor costs for operation and maintenance, which according to the company costs less than it did for the old treatment system. Therefore, the payback period could be even less.

CHAPTER 8.0

WASTE REDUCTION AUDIT PROTOCOL

PRC developed a generic audit protocol that can be used by a PC board manufacturer to assess its own waste reduction opportunities. This section describes the generic protocol that can guide PC board manufacturers through an internal waste reduction audit. The protocol discusses barriers to a successful waste audit, describes the waste reduction audit process, and identifies the data necessary to perform an assessment of the plant's waste problems. The protocol also includes a checklist that can be used to guide an audit team through an audit of the plant.

By developing and implementing a comprehensive waste audit program, a company can effectively assess its waste reduction opportunities. A waste audit is an essential starting point for identifying areas where hazardous waste reduction technologies can be incorporated into an existing manufacturing plant. An audit can identify housekeeping problems and operating inefficiencies that cost little to correct. The critical elements of a successful waste reduction audit program are:

- Management commitment
- Personnel involvement
- Access to background data
- Resources to obtain additional data

Full commitment of management is necessary to perform a comprehensive waste reduction audit program. A commitment in terms of time, personnel, and financing is essential. The waste reduction audit should be planned and administered with input from the company's senior managerial level. Without management support and interest, the waste reduction audit becomes simply an exercise that achieves little actual waste reduction.

Production personnel can be valuable sources of information and they should be available for consultation during the audit. Often times, they can describe actual operating activities in greater detail than supervisory or management personnel. Also, because of their close involvement with the production line, operational personnel may already have ideas of where waste can be reduced through improved housekeeping and process modifications. Finally, if plant personnel are involved in the waste reduction program from the early stages, awareness and cooperation during implementation of the program can be more easily obtained.

Much of the data necessary to perform a waste reduction audit may already exist. However, this information is not always readily available. Existing background data on production rates, material usage, and waste generation often require research and data manipulation. For example, plant personnel may not be aware of the cost of operating their industrial waste treatment system. However, by reviewing treatment chemical purchases and sludge disposal invoices, estimating man-hour requirements, and calculating sewer fees and discharge violation fines, the auditors can quantify the cost of the existing treatment system. All available background information must be identified and obtained to ensure an accurate understanding of the existing plant operations.

A waste reduction audit will inevitably identify areas where necessary information is unavailable. These may include the flow rate for a process, the chemical concentration in a rinse water solution, or the solids concentration in the industrial waste sludge. To obtain this information, flow meters may be needed, sampling and analyses may be required, and even a minor shut down in production may be necessary. The audit team must have the resources available to them to obtain this additional data.

8.1 TYPICAL BARRIERS TO A SUCCESSFUL WASTE AUDIT

Innovative thinking is usually required to identify appropriate waste reduction techniques available to a company. Not all waste reduction opportunities are apparent simply by gathering and analyzing data. Furthermore, potential results cannot always be estimated. Therefore, decisions to implement waste reduction technologies often require certain levels of risk. A company often must overcome barriers to implementing waste reduction techniques that can prevent innovative ideas from being tested. Several of these barriers are as follows:

- o Lack of information about available waste reduction techniques and the benefits that can be achieved.
- o Concerns for upsetting product quality.
- o The "If it ain't broke - don't fix it" attitude.
- o A reluctance to develop innovative ideas because of the fear of failure.
- o The attitude that a new technology will not succeed because it is outside the range of plant personnel expertise.

The audit team must recognize these barriers and be prepared to address them during the audit. This is important to ensure that all potential waste reduction opportunities are identified and assessed. Once again, management commitment to the waste reduction program is essential for overcoming these barriers.

8.2 WASTE REDUCTION AUDIT PROCESS

For a waste audit to be successful it must be comprehensive. Although addressing various waste generation problems one at a time or in a piecemeal manner may provide some degree of waste reduction, this method overlooks the main focus of a successful waste reduction audit, which is to view the manufacturing plant as a single system and to identify the relationships between material usage, production processes, and waste generation. This comprehensive approach can lead to greater reductions in waste and increases in the economic efficiency of the plant.

A comprehensive study of a company's waste problem requires more than a characterization of the various waste streams. Waste reduction is achieved not only at the point of waste generation, but also within the production process and even at the point of choosing production materials. The solution for reducing a particular waste stream often involves modifying material input or production procedures. Therefore, an audit must examine raw material usage, production processes and schedules, and waste handling methods together as one system.

The waste reduction audit process can be broken down into several segments, as described below:

- o Audit team preparation
- o Initial survey
- o Background data analyses
- o Comprehensive plant assessment
- o Evaluation of waste reduction opportunities

If possible, the waste reduction audit should be undertaken by a team of plant personnel. The team concept allows for a more thorough evaluation of the existing operations and encourages discussion of innovative ideas. Since management involvement is essential to the success of the audit, management personnel should be encouraged to participate directly in the audit.

Audit team preparation involves planning the initial survey and becoming familiar with waste reduction opportunities available to the PC board manufacturing industry. The team should discuss the plant's current waste generating problems and identify the production processes that contribute to waste generation. This waste reduction audit protocol provides background information to assist in planning the waste audit and should be reviewed by the audit team.

The initial survey is performed to assimilate existing background information on the plant's operations. Various process lines should be reviewed to identify raw material inputs and waste outputs. The auditors should obtain flow rates for rinsing operations and spent process bath dump schedules. The existing waste handling procedures should also be reviewed. Finally, the initial survey compiles economic information such as raw material costs, energy costs, water and sewer fees, and waste handling costs.

Next, the audit team should review the background information obtained during the initial survey to direct future audit activities. Process flow diagrams should be developed to identify the production processes and show incoming raw materials, product flows, by-product flows, and waste flows. Operations that present opportunities for waste reduction can then be identified. During this review process, the audit team should begin to identify information needed to fully assess the various waste reduction opportunities.

The comprehensive plant assessment is performed to fill data gaps identified during the review of the background information. The audit team should obtain detailed information, such as process bath operation parameters, operator work procedures, and waste characteristics during this step of the audit. Usually, some sampling and analyses activities are needed to obtain this detailed information.

The final step in the waste reduction audit is to assess the feasibility of implementing waste reduction alternatives. All relevant data obtained during both the initial survey and the comprehensive assessment are used to determine which, if any, waste reduction technologies can be incorporated into plant operations. Economic information is used to perform cost/benefit analyses for the various options.

Audit results will not necessarily result in definitive plans for implementing waste reduction techniques. Experiments to modifying the process parameters may still continue. For example, the audit team may decide to test various process baths at low concentrations to minimize the drag-out of process chemicals into the rinse water waste stream. The results of the waste audit should be used to develop an ongoing waste reduction strategy.

The following subsections of this waste reduction audit protocol present specific activities that should be included in the audit. Also, several waste reduction technologies are described and the types of process information needed to assess their applicability to a specific plant are identified.

8.3 IDENTIFYING HAZARDOUS WASTE SOURCES

The starting point for gathering background data is to identify all the hazardous waste sources. Although the most common hazardous waste stream is industrial waste treatment sludge, the industrial waste treatment process is not the source of hazardous waste. The production activities that create the industrial waste are. The various process steps associated with producing a printed circuit board need to be identified and the material inputs and outputs should be described in detail.

The various waste producing sources should be broken down by each distinct process. It is not sufficient to identify the waste sources as rinsing operations and spent process chemical baths. The auditors should separate the sources by their function in the manufacturing process. For example, one source of waste will be effluent from the rinse water system that follows an alkaline cleaning process. It is necessary to divide the various waste sources in this manner so that the specific operating parameters and waste characteristics for each source can be identified later. Also, it is important to not overlook minor sources such as equipment washout waste. The significance of these sources should be evaluated after all relevant data has been obtained. The remainder of this section describes some of the typical waste sources present at a PC board manufacturing plant.

8.3.1 Rinsing Systems

The primary source of hazardous waste is the rinsing operations that follow the process chemical baths. Generally, these wastes contain low concentrations of process chemicals. Treatment of rinse water wastes produces a heavy metal sludge that is a hazardous waste. Rinsing operations should be divided into separate waste sources based on the type of process chemicals that are carried away in the rinse system effluent. This is important for evaluating various rinse recycling and waste segregation opportunities.

8.3.2 Chemical Drag-out

Drag-out from process baths is the source of chemicals entering the rinse water effluent. Although the chemical drag-out ends up in the rinse system effluent, drag-out still needs to be addressed as a separate source because potential waste reduction opportunities for drag-out minimization can be independent of the rinsing operations. Drag-out from each process chemical bath should be identified as a separate waste source. This is important because various drag-out minimization techniques may only be applicable to some of the processes. For example, increased drainage time for work piece racks may not be feasible for some process chemistries where quick oxidation may occur. Also, the use of drag-out tanks is usually only applicable to process baths that operate at an elevated temperature.

8.3.3 Chemical Bath Dumps

Chemical bath dumps should also be identified as hazardous waste sources. Each process bath should be listed whether it is dumped into the industrial waste stream or containerized for transport off-site. The approximate frequency of each dumping should also be listed. The use of chelating chemicals or wetting agents should be noted for each process bath. All of this information will be important for determining the potential for extending the life of a process bath by modifying its operating parameters, or segregating the various baths for selective treatment.

8.3.4 Equipment Cleanout

Equipment cleanout generally includes floor wash down, process bath tank cleaning, electroplating rack cleaning, and any other activities associated with cleaning the plant and the equipment. These wastes usually include rinse waters as well as cleaning solutions such as nitric acid. The auditors should estimate the frequency of these cleaning operations and determine their contribution to overall waste generation.

8.3.5 Spills

Spills may also be a source of hazardous waste. These incidents may be difficult to identify or remember. However, if spills are common they can contribute significantly to the volume of hazardous waste and will usually be easier to identify. Even if plant personnel do not have any information on spills, this source should still be kept in mind when developing a waste minimization plan. Instituting requirements for reporting and documenting future spill incidents will provide valuable historical information for identifying necessary maintenance or operational changes.

8.3.6 Industrial Waste Treatment

The most common form of industrial wastewater treatment used by PC board manufacturers is metals precipitation followed by settling and clarification. This type of treatment generates a sludge that contains metals. Since usually only a small percentage of the sludge solids generated are metal containing compounds, there is also opportunity for waste reduction in the treatment system itself. Therefore, the treatment system should also be reviewed and included as a hazardous waste source.

8.3.7 Samples

Although a chemical product sample provided by a chemical supplier is technically not a waste, unused samples need to be disposed of as if they were waste material. Since these samples may not be wastes, they can be accumulated without concern for violating any hazardous waste storage time requirements. However, these materials must eventually be disposed of, and the costs could be quite significant. The audit team should determine if unusable samples are accumulating at the plant or being fed into the treatment system. The audit team may identify the need to develop a policy on accepting chemical samples.

8.4 CHARACTERIZING WASTE STREAMS

Waste stream characterization should be performed during both the initial survey and the comprehensive assessment of the manufacturing operations. The initial waste characterization activities are performed to develop a qualitative description of the various waste streams. For example, a qualitative description of a rinse system effluent that follows a mild etchant process tank could be: "a slightly acidic, aqueous solution containing low concentrations of peroxide and sulfuric acid, discharged to the industrial treatment plant collection sump." Waste characterization activities performed during the initial survey can usually be accomplished at the same time that the waste sources are identified.

Waste characterization activities performed during the comprehensive assessment are considered quantitative and often will require sampling and analyses. This is performed after the existing background data have been evaluated to identify specific quantitative data needs. The waste characterization data that will be necessary include operating concentrations for the process baths, metals concentrations in various rinse system effluent streams, and percent water content of the treatment sludge. For example, a quantitative description of a rinse system that follows a mild etchant process tank could be: "an aqueous solution containing peroxide and sulfuric acid with a pH of 4.5 discharging to the industrial treatment plant at a rate of 10 gallons per minute for a total of 150 minutes each day."

The remainder of this section describes the type of characterization data needed for the various waste streams.

8.4.1 Rinse System Effluent

Each of the rinsing operations identified as waste generating sources should be characterized. The information that is needed to evaluate waste reduction opportunities include chemical concentration of the effluent, pH, flow rate, and point of discharge. All of these characteristics of the effluent can be determined in-house with the possible exception of the chemical concentration. However, chemical concentration can often be determined stoichiometrically if accurate pH readings are obtained.

8.4.2 Drag-out

Characterization of the drag-out includes chemical concentration and drag-out volume. The chemical concentration of the drag-out can be obtained from the operating parameter requirements used for the various process baths. Drag-out volume is difficult to determine quantitatively. However, several activities can be performed to estimate drag-out rate. Drag-out that could eventually drain from the work piece rack and boards can be measured directly. The work piece rack should be removed and drained the way it normally is with a typical load of boards. Then instead of immersing the rack into a rinse tank, operating personnel can hold it over a catch basin until the drainage stops. The volume of drag-out drained into the catch basin can then be measured.

Drag-out that will normally adhere to a circuit board is usually in the range of 10 to 15 ml/sf. By estimating the square footage of board placed in a work piece rack, the auditors can estimate the drag-out volume that will still be lost after drag-out minimization techniques have been used. The measured volume plus the estimated volume that adheres to the boards is the total drag-out from the process bath.

8.4.3 Spent Chemical Baths

The level of characterization necessary for the various spent chemical process baths depends on the potential alternative handling methods that may be available. For example, a spent sulfuric acid cleaning bath that can possibly be used for pH adjustment in the treatment system may not require much characterization data except its pH. However, if process bath regeneration is a possible option, specific data on the chemical concentration of the bath solution may be necessary.

8.4.4 Equipment Cleanout

The level of characterization necessary for equipment cleanout wastes is also dependent on the potential waste reduction options available. For example, if a nitric acid waste used to clean copper off of plating racks presents potential for copper recovery and nitric acid regeneration, a laboratory analyses of the copper content may be necessary. Alternatively, if extending the life of the nitric acid cleaning solution is a potential waste reduction technique, on-site field testing of the solution is all that may be necessary.

8.4.5 Industrial Waste Treatment Sludge

Characterization of the industrial waste treatment sludge is necessary to determine the efficiency of the treatment system and to assess the potential for dewatering the sludge. The characterization data includes metals content and solids content. Also, analytical data that can be used to determine the contribution of treatment chemicals to the sludge volume should be obtained. For example, if ferrous sulfate is used to break down chelators found in the waste stream so that copper can be precipitated out, the iron content of the sludge should be determined. This data may be helpful for assessing waste segregation and treatment chemical substitution techniques.

8.5 EVALUATING WASTE REDUCTION OPPORTUNITIES

The audit team should begin to identify and evaluate waste reduction opportunities once sufficient background data are obtained. However, specific waste reduction techniques should not be eliminated from further consideration until the comprehensive plant assessment has been completed. Therefore, the evaluation of waste reduction opportunities is a two-step process. First, after background data are obtained, potential waste reduction technologies or procedures should be identified and reviewed. This review process will identify the need for additional data from the comprehensive plant assessment. Second, after completion of the plant assessment, the potential waste reduction technologies or procedures can be fully assessed.

The audit team should evaluate each of the waste reduction opportunities based on two considerations: (1) the feasibility of implementation, keeping in mind the production process parameters necessary to ensure product quality; and (2) the payback of investment, considering cost of implementation and savings in material usage and waste handling costs. Many waste reduction techniques do not require capital investment. What is often required, however, are procedural changes that usually require employee training and cognizance of the need for waste reduction at the plant.

Several techniques are available for evaluating the potential for waste reduction in the various processes used at a PC board manufacturing plant. The remainder of this section discusses methods for determining the feasibility of implementing several waste reduction technologies and procedures.

8.5.1 Improving Rinse Efficiency

Improving rinse efficiency is an effective means of reducing waste generation. Even if the total weight of process chemicals carried away in the wastewater effluent remains constant, reducing the volume of wastewater containing these chemicals will also reduce the resultant sludge. This is most apparent at plants that use untreated water for rinse system feed water. In areas of elevated water hardness, precipitation of natural water contaminants, such as carbonates and phosphates, can produce sludge volumes in excess of the volumes associated with metals removal. Also, the use of most treatment chemicals depends on the volume of wastewater generated. These chemicals usually end up in the sludge. Savings from reduced rinse water use can be obtained in water usage and sewer fees, treatment chemical purchases, and sludge handling costs.

The following equation can be used to assist in determining the most efficient rinse water flow rate for a single stage rinse system:

$$Q = D\ (Cp/Cn)$$

Q = rinse tank flow rate

D = drag-out rate

Cp = chemical concentration on process solution

Cn = allowable chemical concentration in rinse solution

(EPA, 1982a)

The effect on rinse water usage by using multiple stage rinse tanks can be evaluated using another equation:

$$Q = [(Cp/Cn)^{1/n} + 1/n]\ D$$

n = number of rinse tanks in series.

(EPA, 1982a)

The costs associated with reducing rinse water usage vary depending on the method used. The costs incurred to reduce the rinse water feed rate may be limited to those costs associated with the purchase and installation of flow restrictors. Converting a single-stage rinse system into a multistage system may be more costly, however. The purchase of additional tanks and the cost of associated plumbing would be involved. Savings that can be realized from reduced rinse water flow rates include direct reduction of water use and sewer fees and savings in sludge handling costs due to a reduction in sludge generation.

Even if flow restrictors are installed in the systems, excessive volumes of water may still be used because the water may be left on for too long. Automated controls that monitor the chemical concentration in the rinse solution and open the fresh water feed valve when the concentration gets too high should be considered. One PC board manufacturer visited by PRC reported that its water use was cut by two thirds by installing pH meters on all their rinse tanks. The meters are set so that when the pH of the rinse solution reaches a level that is determined to negatively affect rinse efficiency, the meter activates a solenoid which turns on the feed water. When the pH returns to an acceptable level, the meter again activates the solenoid and the water is turned off. The use of pH or conductivity meters is an effective means of controlling water use.

8.5.2 Rinse Water Recycling

Most PC board manufacturing plants generate rinse water effluent that can be recycled for use in other rinsing operations. The most common means of recycling rinse water is the use of an acidic rinse solution for rinsing operations that follow an alkaline cleaning process bath. The efficiency of the rinsing operation following the alkaline bath may actually be improved because the neutralization reaction that will occur aids in removing the alkaline film from the work piece surface.

The audit team should identify which rinse systems produce effluent without contaminants that detract from the rinse water quality at another rinse operation. These can be tested on a batch process by holding the effluent from one rinse system and using it as fresh rinse water on a trial basis. If potential recycling opportunities are identified, the audit team should evaluate possible piping modifications or process line configurations that will allow the company to take advantage of rinse water recycling.

8.5.3 Drag-out Reduction

Most drag-out reduction techniques require simple procedure modifications that do not involve capital investments. The volume of drag-out that can be reduced by making these modifications cannot be accurately predicted. However, since capital expenditures are not usually required, a company can experiment with several techniques to determine how effective the modifications will be. This determination can be accomplished by monitoring the process bath life, the rinse water effluent concentrations, or the volume of sludge generated.

Members of the audit team should experiment with different work piece rack withdrawl methods and rates. They should try positioning the work piece in different ways to improve drainage and experiment with removing the work piece rack from the process bath at a slower rate to determine if drag-out can be reduced. Finally, they should measure the volume of drag-out that can be recovered by increasing drainage time allowed before placing the rack in the rinse bath. The effectiveness of all these techniques can be measured volumetrically by capturing the drag-out in a catch basin after it is removed from the process tank.

Wetting agents can also be used to reduce drag-out losses. Some PC board manufacturers feel that the savings created by drag-out reduction do not justify the potential effects these wetting agents have on their product. Nevertheless, chemical suppliers or other persons knowledgable on the use of wetting agents in PC board manufacturing should be consulted. There may be applications that are appropriate for a company. For example, wetting agents are commonly used in plating bath solutions. With the aid of a chemical supplier, auditors can determine what particular wetting agent provides the greatest reduction in surface tension of the solution.

The audit team may also want to evaluate the process bath operating parameters that are being used. It is possible that the operating concentrations can be reduced. This will minimize drag-out losses. The audit team should realize that the manufacturers' recommendations come from the supplier who is selling the chemicals. The recommendations may not address reducing drag-out loss or extending process bath life. The audit team should attempt to develop a strategy for testing the various process baths at reduced concentrations to determine the most efficient concentration that will provide a quality product and also reduce drag-out loss.

8.5.4 Source Segregation and Process Bath Maintenance

The chemistry of the various process baths should be reviewed by the audit team. Knowledge of how these chemistries affect wastewater treatment and how their process life can be extended should be evaluated. The audit team may be able to identify source segregation techniques and process bath maintenance procedures that can contribute to waste reduction. Audit team members may find helpful information from chemical manufacturers and other PC board manufacturers.

The audit team should identify which process baths contain chelating agents. Although these chelated chemical baths are intended to enhance the metal etching, cleaning, and selective electroless plating during production, they also cause waste treatment to be more difficult and, thus, create a need to use more process chemicals. For example, ferrous sulfate is commonly used to treat wastewaters that contain chelators so that metal ions can be precipitated. The ferrous sulfate is usually added to the wastewater to achieve an iron-to-metal-ion ratio of 8:1. Since the iron is also precipitated as a metal hydroxide sludge, this significantly adds to the volume of sludge generated.

Non-chelated process chemicals are often available to replace the standard chelated chemicals. The audit team should consult with a chemical supplier to evaluate possible material substitutions. Also, the potential for segregating waste streams that contain chelators should be assessed. If this can be done, wastewaters containing chelating agents can be treated separately and ferrous sulfate (or other treatment chemicals used to breakdown chelators) will only be used during treatment of a portion of the wastewater. It should also be noted that the use of non-chelated chemistries may improve the metal removal efficiency of the treatment system. Therefore, it may be easier to comply with sewer discharge requirements.

Process bath maintenance is essential for getting the most use out of a chemical process solution. Audit team members should survey other PC board manufacturers to determine how long some of their electroplating and solder baths can be maintained before dumping is necessary. It is possible that minor adjustments in chemical additions or improved monitoring can increase the life of several of the process baths.

8.5.5 Process Bath Chemical Recovery

Several technologies are available for recovering process chemicals from wastewaters. These include reverse osmosis (RO), ion-exchange (IE), electrolytic recovery (ER), and several others. The feasibility of implementing these recovery techniques is dependent on a variety of parameters specific to the company. The audit team should explore various recovery technologies and review case studies supplied by equipment manufacturers to determine the feasibility of implementing a recovery system.

Manufacturers usually can supply a customer list so that audit team members can discuss the effectiveness of these technologies with companies that use the various types of equipment. The tendency for most companies is to disregard recovery technologies because of the equipment costs or lack of widespread use within the industry. However, the audit team must be prepared to invest time to adequately investigate these possibilities before eliminating them from consideration.

One of the waste reduction options available to PC board manufacturers is recovery of process chemicals from rinse waters. RO and IE systems can be used to selectively recover chemicals from dilute waste streams. The recovered concentrated solution, although usually still more dilute than the original process chemistries, can be used for process bath makeup solution. Also, the effluent from these systems can be recycled as rinse water. The cost considerations necessary to determine the feasibility of such systems includes savings in process chemicals, water usage and sewer fees, treatment chemicals, and sludge handling.

Elemental metal recovery is also a possible resource recovery technology that can be used by PC board manufacturers. These systems can recover solid metal from waste streams which can either be reused on-site (for example plated copper used as an anode in an electroplating line) or sold as metal to a reclaimer. These systems can be used to treat rinse water effluent and cleaning solutions such as nitric acid. Savings can be experienced in reduced water usage (since wastewater effluent may be recycled), recovery of nitric acid, reduction in treatment chemicals used to remove metals from wastewater, reduced sludge handling costs, and pay back from metal recovery.

The feasibility of implementing these various recovery technologies is dependent on the volume and chemical concentration of the various waste streams and the operating parameters of the various process lines. The audit team should explore the potential of utilizing these technologies by contacting equipment manufacturers and, more importantly, companies that have used them.

8.5.6 Waste Treatment Sludge Analyses

Sludge characterization data can provide valuable information for determining the efficiency of the existing treatment system and evaluating the potential for sludge dewatering. The metals concentration of the sludge can provide information on the efficiency of the treatment system, and the solids concentration can provide data for determining if sludge dewatering techniques may be beneficial.

Analytical data describing the metals content of the sludge can be used by the audit team to assess the efficiency of the existing treatment system. If the concentration of each metal in the sludge is known, the auditors can stiochiometrically calculate the total weight of contaminant metal compounds in the sludge. The difference between the total dry weight of the sludge and the total dry weight of contaminant metal compounds will indicate the dry weight of non-metal containing compounds in the sludge. This portion of the sludge is what may be reduced by the company by improving the efficiency of the treatment system. For example, if the company uses ferrous sulfate in the treatment system to breakdown chelators, the total weight of iron compounds in the sludge is an indicator of the impact chelated process chemistries have on sludge volume. The cost of the ferrous sulfate and the disposal of the additional sludge can provide economic data to evaluate the benefits of using non-chelated process chemistries or segregating chelated chemistries.

Sludge volume can be significantly reduced by increasing the solids concentration. The solids content can be increased through mechanical dewatering and sludge drying. The audit team can assess the cost effectiveness of incorporating sludge dewatering techniques by comparing the savings on sludge handling costs to the costs of purchasing and operating the dewatering equipment.

8.6 WASTE REDUCTION AUDIT CHECKLIST

This subsection describes how the waste reduction audit checklist presented in Appendix D can be used when performing a waste reduction audit at a PC board manufacturing plant. The checklist contains: (1) tables for summarizing material usage, waste generation, and production process data; (2) questions for identifying potential waste reduction opportunities; and (3) tables for evaluating waste reduction technologies identified during the audit.

The checklist should be reviewed by the audit team prior to beginning the audit. The information requested in the data summary tables (Tables D2.1,D2.2,D4.1, and D4.2) should be obtained during the initial plant survey. The auditors should then attempt to answer the checklist questions and begin filling in the waste reduction technology tables during the background data review. During this portion of the audit, team members will be able to identify additional data needs necessary to answer the remaining checklist questions and complete the tables. These additional data needs will be obtained during the comprehensive plant assessment.

After the plant assessment is completed, the audit team can determine the feasibility of implementing the various waste reduction techniques identified during the audit. The audit team should utilize the expertise of equipment suppliers and process and treatment chemical suppliers to perform these evaluations. Finally, economic data should be used to perform a cost/benefit analysis on those waste reduction techniques that display potential for implementation. A cost/benefit worksheet is provided at the end of the checklist to aid in performing cost/benefit analyses.

CHAPTER 9.0

SUMMARY OF PLANT AUDITS

PRC performed waste reduction audits at three PC board manufacturing plants. The information obtained during these audits was used to: (1) identify waste reduction technologies available to PC board manufacturers, and (2) develop a generic waste audit protocol that can be used by PC board manufacturers to perform their own audits.

Each of the three PC board manufacturing companies is considered small in terms of size and average rate of circuit board production. Generally, these companys maintain approximately 8,000 to 10,000 square feet of building space and produce around 3,000 to 4,000 square feet of board each month.

The three companys are all prototype PC board manufacturers, specializing in small jobs, usually 25 to 100 boards, with a quick turn-around. Because of this type of manufacturing, production rates, material usage, and waste generation rates fluctuate.

Performance of the three waste audits provided valuable information on the potential for implementing waste reduction technologies into a PC board manufacturing plant. The audits also provide information on the limitations to waste reduction inherent to the industry. The audit team observed several waste reduction techniques being used at these plants and also identified potential waste reduction opportunities that the plants have not yet employed. Potential waste reduction opportunities available were presented in reports submitted to each company. Although not completed as yet, management and production personnel will be requested to review the report and offer their opinion on the feasibility of implementing the recommended waste reduction technologies.

This chapter summarizes the results of the three waste reduction audit studies. Section 9.1 describes the observations of the industry's existing waste management philosophies and the obstacles to waste reduction that the industry faces. Section 9.2 describes recommendations for waste reduction developed for the three companies. Appendix B contains copies of the waste audit reports submitted to each company.

9.1 WASTE AUDIT FINDINGS

Although the companies audited are considered small PC board manufacturers, the production methods, materials used and wastes generated are similar to larger PC board manufacturers. Therefore, many of the observations made during the audit can be applied to larger firms. When an observation in this report is not applicable to all sizes of companies, the applicable category or categories are indicated.

• The primary waste management concern of PC board manufacturers is meeting wastewater effluent requirements for discharges to a POTW. Limitations on the chemical concentrations that can be discharged to the sanitary sewer have increased the demands on a plant's industrial waste treatment system. In addition, the fines and potential penalties associated with violating these discharge requirements have become more severe in the last few years. As a result, PC board manufacturers place a high priority on maintaining their industrial waste treatment system.

In response to this growing concern, process chemical manufacturers are beginning to study the impact their products have on industrial waste treatment. Much of the research and development these chemical companies perform relates to the treatability of the chemistries once they enter the wastewater stream (Foggia, 1987). As a result, chelators used in many process chemistries are either being eliminated from new products or being replaced with mild chelators. However, many of these alternative process chemistries have not yet been universally accepted.

Although the emphasis is not placed on the industrial waste treatment may have a positive impact on reducing hazardous waste generation because of the reduction in the use of chelators, negative impacts on hazardous waste generation are possible. First, upgrading of industrial treatment systems may require large capital investments, making capital unavailable for waste reduction technologies. Second, if a company is able to meet its discharge requirements, it may be opposed to instituting waste reduction techniques for fear of upsetting the treatment system. For example, companies would be hesitant to use alternative treatment chemicals for fear that the modifications could cause their effluent to exceed discharge standards. Also, companies may avoid improving rinse efficiency, which would produce a more concentrated waste stream, for fear of overloading the treatment system.

Another concern common to most PC board manufacturers is maintaining process bath chemistries to ensure product quality. In general, plant personnel are resistant to process modifications that have the potential to impact their process baths. For example, all three companies audited use drag-out tanks following their electro-plating lines. These companies, however, do not reuse the drag-out solution to replenish their electroplating baths out of fear of contaminating their process baths. Plant personnel typically believe that the potential cost associated with spoiling a process bath exceeds the potential benefits from reusing the drag-out solution. The companies are also hesitant to experiment with lower process bath concentrations for fear of upsetting the product quality.

Although process chemical manufacturers have begun to study the impact of these chemistries on wastewater treatment, no research has been conducted on the impact of these chemistries on waste generation (Foggia, 1987). Many waste reduction technologies available to the PC board industry require modifications to process bath operating parameters or handling procedures. However, the information necessary to assess the impacts of these technologies on the process baths and to overcome the limitations the process baths present is not generally available from chemical manufacturers. For example, chemical manufacturers do not provide data describing the drag-out rates for specific process chemistries operated at various concentrations and temperatures. Also, many process baths cannot reuse drag-out solutions because the chemistries are affected by drag-out. Research has not been conducted to develop chemistries that can utilize drag-out reuse technologies. Because of the increasing concern of PC board manufacturers over waste disposal costs and liabilities, however, the chemical manufacturing industry is now beginning to conduct research and development to address waste generation considerations.

PRC did identify examples of chemical manufacturers addressing waste reduction concerns. For example, many suppliers provide process chemicals that can be returned to them when the chemicals become spent. This can reduce waste treatment and disposal costs for a company. Also, one chemical manufacture provides small waste treatment units for removing copper from its spent electroless copper bath. If a municipality allows the discharge of chelators into the sewer, the effluent can be directly discharged to the sanitary sewer (Stone, 1987). Chemical suppliers indicate that they are beginning to direct their product development efforts toward products that have less impact on waste generation.

Small PC board manufacturers have several common limitations to implementing some waste reduction technologies. For example, because their floor space is limited, small companies cannot feasibly use multiple stage counter-current rinsing. Also, because these companies use manually operated work piece racks, control of drag-out and proper rinsing is more difficult than if their production lines were automated.

Another common characteristic of smaller PC board manufacturing firms is their overall lack of data pertaining to several process parameters. None of the companies visited knew the flow rates through their various rinse systems. These firms also did not know the drag-out rates for any of their process baths. Also, they were not aware of which chemical concentration levels in the rinse solutions would allow for acceptable work piece rinsing.

These same companies, however, were knowledgeable about data directly related to waste management costs. For example, data describing the volume of wastes generated, waste disposal costs, and costs for operating the treatment systems were all available. Therefore, it appears that PC board manufacturers are aware of the direct costs of waste treatment and handling but are not as aware of the production processes that contribute to waste generation. This inhibits the ability to implement process modifications intended to reduce waste generation.

9.2 WASTE AUDIT RESULTS

After completing each waste reduction audit, the auditors prepared a report that described the plant's waste generation and handling procedures and provided recommendations for implementing various waste reduction technologies. This section summarizes the waste reduction recommendations developed for the three companies audited by PRC. Appendix B contains the audit reports written for each company.

The three PC board manufacturing firms included in the waste audit study use a variety of a waste management technologies. This allowed the audit team to observe waste reduction at various levels of implementation. One of the companies uses an ion exchange unit for treating its wastewater while the other two companies utilize conventional sludge generating treatment processes. One of the firms visited by the audit team uses pH/conductivity meters for automatically controlling water flow through its rinse systems. This company also uses other water conservation techniques such as flow restrictors and pressure activated water flow switches. Another plant does not use any of these water conservation techniques and appears to operate its rinse tanks at an excessively high flow rate. One of the companies treats its process water prior to use in the production processes while the other two do not. Because of the treatment system the plant uses, however, a comparison of sludge generation rates between the companies was not possible. One of the plants utilizes a multiple tank electroplating rack cleaning line, while the other two use a single tank for cleaning racks. The multiple tank system produced significantly less nitric acid waste than the single tank cleaning systems. Finally, one company uses a bag press sludge dewatering unit and was able to increase the solids content of its sludge to approximately 35 percent. The other company that generates an industrial waste treatment sludge does not utilize any mechanical dewatering techniques and can only obtain a solids concentration of approximately 11 percent in its sludge.

As discussed in Section 9.1, none of the plants visited pay close attention to process chemical losses due to drag-out. The auditors observed production personnel at one plant quickly removing work piece racks from process baths and allowing only a few seconds for drainage prior to rinsing. None of the companies actively promoted drag-out reduction to employees by training them on proper work piece rack handling procedures.

All three companies generate a hazardous waste stream that can potentially be eliminated through material substitution. Reflow oil, which is used to form a smooth, uniform film of solder on the printed circuit board, is containerized and handled as a hazardous waste by each company. Several chemical suppliers now provide reflow oil products that can either be returned to the supplier or treated and discharged to the POTW when they become spent.

One plant was found to produce an excessive volume of sludge in its wastewater treatment system. The process chemistries used by the company contain chelators that require reduction with ferrous sulfate during wastewater treatment to precipitate contaminant metals. The ferrous sulfate contributes to sludge volume because iron precipitates as ferrous hydroxide during treatment. Analytical data on the sludge indicated that the ferrous hydroxide contributed over 30 percent of the solids in the company's sludge. Therefore, the use of non-chelated process chemistries and/or the segregation of chelated and non-chelated waste streams could significantly reduce sludge generation at this plant. Since the company spends over $250 per month on ferrous sulfate purchases, these waste reduction options could also save the company money on treatment chemical purchases.

Several waste reduction techniques were recommended to all three companies, while other recommendations were unique to a company's specific waste problem. The following list describes the waste reduction recommendations developed for the three firms included in this waste audit study.

- Use recyclable or treatable reflow oil to replace product that becomes a hazardous waste when spent.
- Operate the rinse systems as batch rinse tanks instead of flow through rinse tanks.
- Reduce the flow rate through the rinse tanks.
- Install flow restrictors and automated flow control devices as part of each rinse system.
- Train personnel on proper work piece rack withdrawal and drainage procedures to minimize drag-out loss.
- Operate process baths at the lowest possible concentration and the highest practical temperature.
- Utilize multiple stage cleaning systems for cleaning electroplating racks.
- Recycle photoresist stripper waste by decanting or filtering the contaminated stripper bath.

- Reuse acidic rinse water effluent as influent for rinse systems that follow alkaline cleaning baths.

- Recycle rinse water through use of an alternative treatment technology such as ion-exchange and activated carbon treatment.

- Segregate non-chelated waste streams from chelated waste streams.

- Dewater sludge to increase solids concentration and decrease sludge volume.

CHAPTER 10.0

CURRENT REGULATORY ASPECTS OF HAZARDOUS WASTE MANAGEMENT

A variety of Federal, State, and local laws, regulations and ordinances influence hazardous waste management. Some of these requirements directly promote waste reduction by increasing the costs of other options, such as treatment or disposal. These requirements include the State of California's land disposal restrictions and standards set for generators; transporters; and owners or operators of treatment, storage or disposal (TSD) facilities. Other requirements indirectly affect waste reduction because they command the immediate attention of a waste generator or TSD owner/operator due to potential regulatory enforcement actions and fines. Compliance with these requirements is given a higher priority, in terms of capital investments and time, than waste reduction. Examples of these requirements include: pretreatment requirements set by local POTWs that receive treated effluents from industrial waste treatment systems; and local ordinances that regulate the storage of both hazardous materials and wastes. Appendix E identifies several environmental regulations that affect PC board manufacturers.

The restrictions on the land disposal of many wastes has increased the cost of hazardous waste disposal. The land disposal restrictions that affect PC board manufacturers have been in effect for several years. For example, the restrictions on the land disposal of liquid wastes containing toxic metals and/or acids began on January 1, 1984 (Section 66905 CAC). These restrictions have caused increases in disposal costs, since these wastes now require some form of treatment prior to land disposal. The impact of increased waste disposal costs should have a positive impact on the implementation of waste reduction technologies.

California's hazardous waste management laws and regulations affect the generation, transportation, treatment, storage, and disposal of hazardous wastes. Many of the permitting requirements, including training, contingency plans, and record keeping, are applicable to plants that store hazardous wastes for more than

90 days. Businesses that store wastes for 90 days or less, therefore, face fewer requirements. However, several manufacturers feel the 90-day accumulation limit places constraints on their waste management practices.

Several PC board manufacturers have stated that waste transport fees are based on a minimum pick up of ten to fifteen 55-gallon drums. Quantities less than these are charged a higher transport rate. Many small PC board manufacturers have trouble meeting the 90-day accumulation restriction while also attempting to accumulate enough drums to minimize waste transport costs. Implementing waste reduction technologies would cause even more difficulty in meeting the 90-day accumulation limit. Alternatively, since the 90-day accumulation time begins when 100kg of hazardous waste or 1 kg of extremely hazardous waste are accumulated, quantities less than these are not subject to the 90-day accumulation limit. Therefore, for small quantity generators, these accumulation restrictions may encourage waste reduction.

As previously stated in Section 9.1, the primary waste management concern of PC board manufacturers is meeting wastewater effluent requirements for discharges to the local POTW. Limitations on the chemical concentrations that can be discharged to the sanitary sewer have increased the demands on the plant's industrial waste treatment system. In addition, the potential fines and other penalties associated with violating these discharge requirements have become more severe in the last few years. As a result, PC board manufacturers place a high priority on maintaining their industrial waste treatment systems. The emphasis these businesses place on pretreatment requirements, causes waste reduction to be a lower priority.

Another statutory requirement that has become a priority for PC board manufacturers is the recent passage of California's citizens right-to-know legislation. The state law requires local governments to implement hazardous material storage programs to regulate industry (Chapter 6.95, CHSC). These regulatory programs may affect PC board manufacturers in two ways: (1) compliance with the local programs will often require investments to upgrade the plants and will require time for the plants to develop their permit applications and hazardous material management plans; and (2) since the local programs permit fees are based on the type and quantity of hazardous materials stored at a plant, decisions on source segregation and batch treatment of wastes and the storage and use of hazardous materials will be influenced by these local ordinances. The impact of the first item may be a reduction in the capital and time PC board manufacturers are able to allocate to address waste reduction. The second item could both discourage and encourage waste reduction. Segregation of materials and batch treatment may require additional storage tanks. This could increase a business' storage permit fees and its exposure to liability costs due to spills or other releases. Alternatively, storage permit fees may encourage plants to reduce their material inventories and waste generation to minimize their permit costs.

Because the cost of waste handling and disposal has increased in recent years, waste reduction has become more attractive to businesses. Alternatively, because other waste management regulations impose enforceable regulatory requirements and fines for non-compliance, waste reduction receives a lower priority than these other regulations. The businesses included in the waste reduction audit study all showed an interest in waste reduction. However, they all placed a higher priority on local wastewater effluent discharge requirements and hazardous material storage requirements.

CHAPTER 11.0

LIST OF ACRONYMS

DHS	-	California Department of Health Services
EDTA	-	Ethylenediaminetetraacetic acid
IE	-	Ion Exchange
PC	-	Printed Circuit
POTW	-	Publicly Owned Treatment Works
RO	-	Reverse Osmosis

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APPENDIX A

SUPPLEMENT

GUIDE TO WASTE MINIMIZATION IN THE PRINTED CIRCUIT BOARD MANUFACTURING INDUSTRY

With Worksheets for Conducting a Waste Minimization Assessment of a Printed Circuit Board Manufacturing Facility

by

Jacobs Engineering Group Inc.
Pasadena, California 91101-3063
under subcontract to Radian Corporation

Contract 68-02-4286

Project Officer

Lisa M. Brown
Waste Minimization, Destruction and
Disposal Research Division
Risk Reduction Engineering Laboratory
Cincinnati, Ohio 45268

This study was conducted in cooperation with
California Department of Health Services
Toxic Substances Control Division
Alternative Technology Section
Sacramento, California 95814

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

State of California—Health and Welfare Agency

Department of Health Services

ORDER FORM FOR CALIFORNIA HAZARDOUS WASTE CONTROL LAWS AND REGULATIONS

Copies of hazardous waste control laws and regulations *administered by the California Department of Health Services* may be ordered by completing the form below and mailing it with the applicable payment to:

Department of General Services, Publications Section
P.O. Box 1015
North Highlands, CA 95660
(916) 973-3700

The laws and regulations are *not* identical, so both are generally needed to obtain complete information.

The laws (Chapters 6.5 through 6.98, Division 20, California Health and Safety Code) were enacted by the Legislature. Recent history indicates that the laws change to some extent each year, usually effective January first. To keep up to date with the laws, reorder them each year, because no amendment service is available.

The regulations (Chapter 30, Division 4, Title 22, California Code of Regulations) were adopted by the Department of Health Services within the scope of the DHS' authority under the laws. The regulations may change at any time during the year according to specified administrative procedures. Therefore, continuous amendment service is available by subscription. The amendment service is useful only in conjunction with the complete regulations (i.e., Division 4, Title 22, CCR).

I. Please check all applicable boxes and complete all applicable blanks.

☐ Please send me ______ copy(ies) of *Item No. 7540-958-1016-6, Hazardous Waste Control Law* (Chapters 6.5 – 6.98, Division 20, Health and Safety Code), at $25.00 per copy, including postage, taxes, and handling costs. $ ______

☐ Please send me ______ copy(ies) of the regulations (Division 4, Title 22, California Code of Regulations [CCR]) at $8.48 per copy, including postage, taxes, and handling costs. (Item Number 0030-0224-7) $ ______

☐ Please accept my ______ subscription(s) to the continuous amendment service for the regulations (Division 4, Title 22, CCR) at $12.00 per subscription per year, including postage and handling costs. The complete regulations must be ordered separately by checking the applicable box. (Item Number 22-04-00) $ ______

Make check or money order for the total amount payable to: State of California.

TOTAL AMOUNT $ ______

II. Please print or type your mailing address and telephone number below; then sign and date the form.

Name/Company Name ______

Attention ______

Address ______

City ______ State ______ Zip ______

Telephone Number ______ (In case we need to contact you about your order)

Signature	Date

DHS 8400 (2/89)

WHERE TO GET HELP: CALIFORNIA STATE AGENCIES

EMERGENCY SERVICES

Spills (24-hour)	800/852-7550
Emergency Planning	916/427-4287

HEALTH SERVICES
Toxic Substances Control

Information

EPA ID number	916/324-1781
Manifest	916/324-1781
Oil (Used) Recycling	916/324-1807
Hazardous Waste	
Exchange	916/324-1807
Recycling	916/324-1807
Transport	916/324-2430

Regional Offices

Region 1, TSCP
10151 Croydon Way
Sacramento, CA 95827
(916) 855-7700

Region 1, TSCP
(Surveillance, Enforcement & Site Mitigation only)
5545 East Shields Avenue
Fresno, CA 93727
(209) 445-5938

Region 2, TSCP
700 Heinz Avenue, Bldg. F
Berkeley, CA 94710
(415) 540-2122

Region 3, TSCP
1405 North San Fernando Blvd.
Burbank, CA 91504
(818) 567-3000

Region 4, TSCP
245 West Broadway, Suite 360
Long Beach, CA 90802
(213) 590-5950

AIR RESOURCES BOARD

1102 Q Street
Sacramento, CA 95814
916/322-2990

HIGHWAY PATROL

Transport	916/327-3310

WASTE MANAGEMENT BOARD

1020 Ninth Street, #300
Sacramento, CA 95814
916/322-3330

Oil (Used) Recycling	800/553-2962

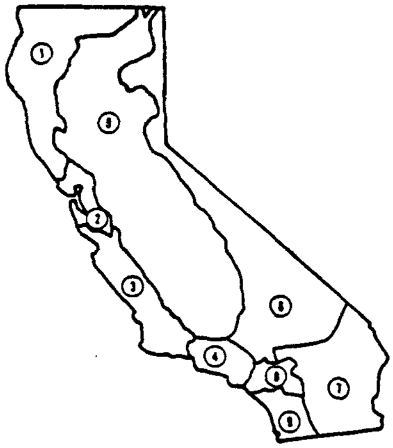
WATER RESOURCES CONTROL BOARD

901 P Street
Sacramento, CA 95814
916/322-3132

Water Quality	916/445-9552
Underground Tanks	916/324-1262

WATER QUALITY CONTROL BOARDS

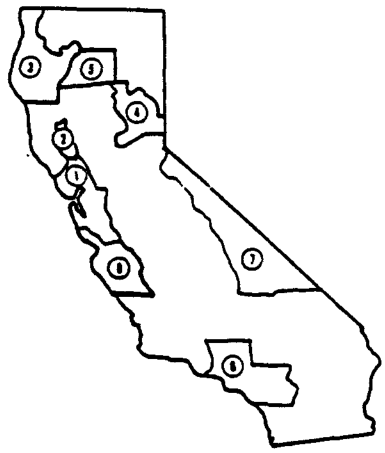
Region 1	707/576-2220
Region 2	415/464-1255
Region 3	805/549-3147
Region 4	213/620-4460
Region 5	
(Sacramento)	916/361-5600
(Fresno)	209/445-5116
(Redding)	916/224-4845
Region 6	
(South Lake Tahoe)	916/544-3481
(Victorville)	619/241-6583
Region 7	619/346-7491
Region 8	714/782-4130
Region 9	619/265-5114



LOCAL AGENCIES

AIR QUALITY MAINTENANCE DISTRICTS

1: Bay Area	415/771-6000
2: Lake County	707/263-7000
3: North Coast Unfd	707/443-3093
4: Northern Sierra	916/265-1398
5: Shasta County	916/225-5674
6: South Coast	818/572-6200



AIR POLLUTION CONTROL DISTRICTS

Amador County	209/223-6406
Butte County	916/891-2882
Calaveras County	209/754-6460
Colusa County	916/458-5891
El Dorado County	916/621-5897
Fresno County	209/445-3239
Glenn County	916/934-4651
7: Great Basin Unfd	619/872-8211
Imperial County	619/339-4314
Kern County	805/861-3682
Kings County	209/584-1411
Lassen County	916/257-8311
Madera County	209/675-7823
Mariposa County	209/966-3689
Mendocino County	707/463-4354
Merced County	209/385-7391
Modoc County	916/233-3939
8: Monterey Bay Unfd	408/443-1135
Northern Sonoma	707/433-5911
Placer County	916/889-3159
Sacramento County*	916/386-6650
San Bernardino Cnty	619/243-8200
San Diego County	619/694-3307
San Joaquin County	209/468-3473
San Luis Obispo Cnty	805/549-5912
Santa Barbara County	805/967-4872
Siskiyou County	916/842-8029
Stanislaus County	209/525-4152
Sutter County	916/741-7500
Tehama County	916/527-4504
Tulare County	209/733-6438
Tuolumne County	209/533-5693
Ventura County	805/654-2667
Yolo-Solano County	916/666-8146
Yuba County	916/741-6484

*Environmental Management Dist.

WHERE TO GET HELP: FEDERAL AGENCIES

The U. S. Environmental Protection Agency has written several reports which will help you reduce, recycle or reuse hazardous waste.

You can order the following set for $152 from the National Technical Information Service, Springfield, Virginia, 22161 (703/ 487-4650). The order number is PB87-114328. Volume 1 is the Executive Summary & Fact Sheet.

> Minimization of Hazardous Waste, Vols. 1-5.

You can order the following three Waste Minimization Audit Reports from NTIS. Or you can order the executive summaries from EPA/ATD/HWERL, 26 West St. Clair Street, Cincinnati, Ohio, 45268.

> Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex, (NTIS PB88-107180/GAR).

> Case Studies of Minimization of Solvent Waste from Parts Cleaning and from Electronic Capacitor Manufacturing Operations, (NTIS PB87-227013).

> Case Studies of Minimization of Cyanide Wastes from Electroplating Operations, (NTIS PB87-229662).

You'll find EPA (and other) offices listed to the right.

U. S. DEPARTMENT OF TRANSPORTATION

Information Hotline: 202/366-4488
Southern California: 818-405-7110
Northern California: 916/551-1300

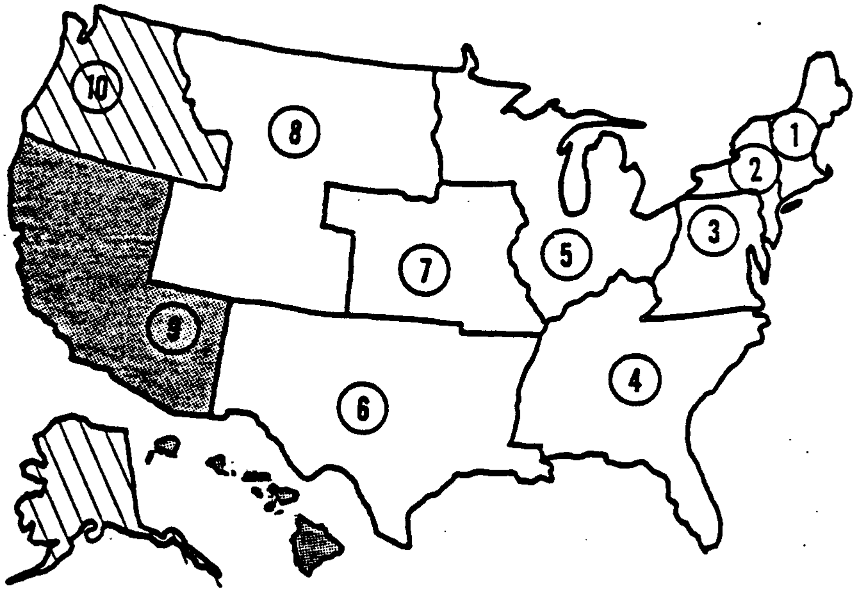
U. S. COAST GUARD

National Response Center
800/424-8802

U. S. PUBLIC HEALTH SERVICE

National Health Information
800/336-4797

U. S. ENVIRONMENTAL PROTECTION AGENCY



Region 1
John F. Kennedy Building
Boston, MA 02203
617/565-3715

Region 2
26 Federal Plaza
New York, NY 10278
212/264-2525

Region 3
841 Chestnut Street
Philadelphia, PA 19107
215/597-9800

Region 4
345 Courtland Street
Atlanta, GA 30365
404/347-4727

Region 5
230 South Dearborn Street
Chicago, IL 60604
312/353-200

Region 6
1445 Ross Avenue
Dallas, TX 75202
214/655-6444

Region 7
726 Minnesota Avenue
Kansas City, KS 66101
913/236-2800

Region 8
999 Eighteenth Street
Denver, CO 80202
303/293-1603

Region 9**
215 Fremont Street
San Francisco, CA 94105
415/974-7460

Region 10
1200 Sixth Avenue
Seattle, WA 98101
206/442-5810

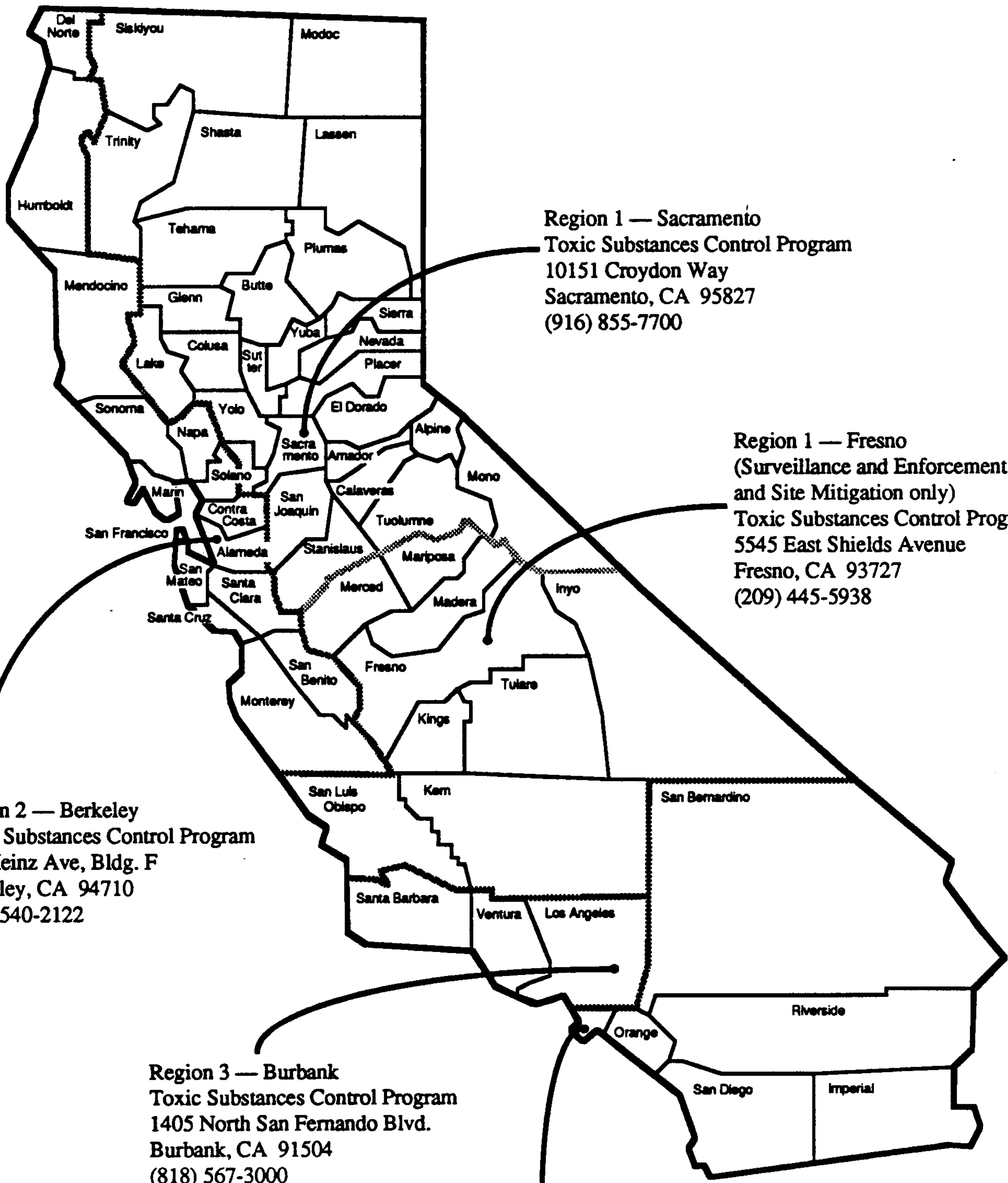
EPA Hotlines

RCRA/Superfund:	800/424-9346
Small Business Ombudsman:	800/368-5888
Title III:	800/535-0202

****Region 9 Information**

Asbestos:	415/974-7551
Emergency Response:	415/974-8131
Industry Aid:	415/974-7473
Radon:	415/974-8076

Toxic Substances Control Program Regional Offices



Region 1 — Sacramento
Toxic Substances Control Program
10151 Croydon Way
Sacramento, CA 95827
(916) 855-7700

Region 1 — Fresno
(Surveillance and Enforcement
and Site Mitigation only)
Toxic Substances Control Program
5545 East Shields Avenue
Fresno, CA 93727
(209) 445-5938

Region 2 — Berkeley
Toxic Substances Control Program
700 Heinz Ave, Bldg. F
Berkeley, CA 94710
(415) 540-2122

Region 3 — Burbank
Toxic Substances Control Program
1405 North San Fernando Blvd.
Burbank, CA 91504
(818) 567-3000

Region 4 — Long Beach
Toxic Substances Control Program
245 West Broadway, Suite 360
Long Beach, CA 90802
(213) 590-5950

WASTE REDUCTION TECHNICAL/FINANCIAL ASSISTANCE PROGRAMS

The EPA's Office of Solid Waste and Emergency Response has set up a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA):

(800) 242-9346 (outside the District of Columbia)

The following states have programs that offer technical and/or financial assistance in the areas of waste minimization and treatment.

Alabama
Hazardous Material Management and Resources Recovery Program
University of Alabama
P.O. Box 870203
Tuscaloosa, AL 35487-0203
(205) 348-8401

Alaska
Alaska Health Project
Waste Reduction Assistance Program
431 West Seventh Avenue, Suite 101
Anchorage, AK 99501
(907) 276-2864

Arkansas
Arkansas Industrial Development Commission
One State Capitol Mall
Little Rock, AR 72201
(501) 371-1370

California
Alternative Technology Division
Toxic Substances Control Program
California Department of Health Services
P.O. Box 942732
Sacramento, CA 94234-7320
(916) 324-1807

Connecticut
Connecticut Hazardous Waste Management Service
Suite 360
900 Asylum Avenue
Hartford, CT 06105
(203) 244-2007

Connecticut Department of Economic Development
865 Brook Street
Rocky Hill, CT 06067
(203) 258-4200

Georgia
Hazardous Waste Technical Assistance Program
Georgia Institute of Technology
Georgia Technical Research Institute
Environmental Health and Safety Division
O'Keefe Building, Room 027
Atlanta, GA 30332
(404) 894-3806

Environmental Protection Division
Georgia Department of Natural Resources
Floyd Towers East, Suite 1154
205 Butler Street
Atlanta, GA 30334
(404) 656-2833

Illinois
Hazardous Waste Research and Information Center
Illinois Department of Energy and Natural Resources
1808 Woodfield Drive
Savoy, IL 61874
(217) 333-8940

Illinois Waste Elimination Research Center
Pritzker Department of Environmental Engineering
Alumni Building, Room 102
Illinois Institute of Technology
10 West 35th Street
Chicago, IL 60616
(313) 567-4250

Indiana
Environmental Management and
Education Program
Young Graduate House, Room 120
Purdue University
West Lafayette, IN 47907
(317) 494-5036

Indiana Department of Environmental
Management
Office of Technical Assistance
P.O. Box 6015
105 South Meridian Street
Indianapolis, IN 46206-6015
(317) 232-8172

Iowa
Center for Industrial Research and Service
205 Engineering Annex
Iowa State University
Ames, IA 50011
(515) 294-3420

Iowa Department of Natural Resources
Air Quality and Solid Waste
Protection Bureau
Wallace State Office Building
900 East Grand Avenue
Des Moines, IA 50319-0034
(515) 281-8690

Kansas
Bureau of Waste Management
Department of Health and Environment
Forbes Field, Building 740
Topeka, KS 66620
(913) 296-1590

Kentucky
Division of Waste Management
Natural Resources and Environmental
Protection Cabinet
18 Reilly Road
Frankfort, KY 40601
(502) 564-6716

Louisiana
Department of Environmental Quality
Office of Solid and Hazardous Waste
P.O. Box 44307
Baton Rouge, LA 70804
(504) 342-1354

Maryland
Maryland Hazardous Waste Facilities Siting
Board
60 West Street, Suite 200 A
Annapolis, MD 21401
(301) 974-7281

Maryland Environmental Services
2020 Industrial Drive
Annapolis, MD 21401
(301) 974-7281

Massachusetts
Office of Safe Waste Management
Department of Environmental Management
100 Cambridge Street, Rm. 1094
Boston, MA 02202
(617) 727-3260

Source Reduction Program
Massachusetts Department of Environmental
Quality Engineering
1 Winter Street
Boston, MA 02108
(617) 292-5982

Michigan
Resource Recovery Section
Department of Natural Resources
P.O. Box 30028
Lansing, MI 30241
(517) 373-0540

Minnesota
Minnesota Pollution Control Agency
Solid and Hazardous Waste Division
520 Lafayette Road
St. Paul, MN 55155
(612) 296-6300

Minnesota Technical Assistance Program
University of Minnesota
420 Delaware SE
P.O. Box 197 Mayo
Minneapolis, MN 55455
(612) 625-9677

Minnesota Office of Waste Management
1350 Energy Lane, Suite 201
St. Paul,MN 55108
(612) 649-5750

Missouri
State Environmental Improvement and Energy Resources Authority
225 Madison
P.O. Box 744
Jefferson City, MO 65102
(314) 751-4919

New Jersey
New Jersey Hazardous Waste Facilities Siting Commission
28 West State Street, Room 614
Trenton, NJ 08608
(609) 292-1459

Hazardous Waste Advisement Program
Bureau of Regulation and Classification
Division of Hazardous Waste Management
New Jersey Department of Environmental Protection
401 East State Street, CN 028
Trenton, NJ 08625
(609) 292-8341

Risk Reduction Unit
Division of Science and Research
New Jersey Department of Environmental Protection
401 East State Street,
6th Floor, CN 409
Trenton, NJ 08625
(609) 984-6070

New York
Department of Energy Conservation
Division of Hazardous Substances Regulation
Bureau of Hazardous Waste Program Development
50 Wolf Road, Room 231
Albany, NY 12233-7253
(518) 457-3273

North Carolina
Pollution Prevention Program
Department of Environment, Health, and Natural Resources
P.O. Box 27687
512 North Salisbury Street
Raleigh, NC 27611
(919) 733-7015

Governor's Waste Management Board
325 North Salisbury Street
Raleigh, NC 27611
(919) 733-9020

North Carolina Technical Assistance Unit Hazardous Waste Section
North Carolina Department of Environment, Health and Natural Resources
401 Oberlin ROad
P.O. Box 2091
Raleigh, NC 27602
(919) 733-2178

Ohio
Division of Solid and Hazardous Waste Management
Ohio Environmental Protection Agency
1800 Watermark Drive
Columbus, OH 43215
(614) 644-3020

Ohio Technology Transfer Organization
77 South High, 26th Floor
Columbus, OH 43266-0330
(614) 466-4286

Oklahoma
Industrial Waste Elimination Program
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
(405) 271-7353

Oregon
Oregon Hazardous Waste Reduction Program
Department of Environmental Quality
811 Southwest Sixth Avenue
Portland, OR 97204
(503) 229-5913

Pennsylvania
Pennsylvania Technical Assistance Program
Williams Street Building #101
University Park, PA 16801
(814) 865-0427

Center of Hazardous Material Research
University of Pittsburgh
320 William Pitt Way
Pittsburgh, PA 15238

Bureau of Waste Management Pennsylvania
Department of Environmental Resources
P.O. Box 2063
Fulton Building
3rd and Locust Streets
Harrisburg, PA 17120
(717) 787-6239

Rhode Island
Ocean State Cleanup and Recycling Program
Rhode Island Department of Environmental Management
83 Park Street
Providence, RI 02908-5003
(401) 277-3434

Center for Environmental Studies
Brown University
P.O. Box 1943
135 Angell Street
Providence, RI 02912
(401) 863-3449

Tennessee
Center for Industrial Services
106 Student Services
University of Tennessee
Knoxville, TN 37996
(615) 974-3018

Virginia
Office of Policy and Planning
Virginia Department of Waste Management
11th Floor, Monroe Building
Richmond, VA 23219
(804) 225-2667

Washington
Hazardous Waste Section
4224 Sixth Avenue SE
(Rowesix Bldg. 4)
Lacy, WA 98503
(206) 459-6322

Wisconsin
Bureau of Solid Waste Management
Wisconsin Department of Natural Resources
P.O. Box 7921
101 South Webster Street
Madison, WI 53707
(608) 266-2699

Wyoming
Solid Waste Management Program
Wyoming Department of Environmental Quality
Herchler Building, 4th Floor
West Wing
122 West 25th Street
Cheyenne, WY 82002
(307) 777-7752

APPENDIX D

WASTE REDUCTION AUDIT CHECKLIST

FOR

PRINTED CIRCUIT BOARD MANUFACTURING PLANTS

TABLE OF CONTENTS

LIST OF TABLES

WASTE REDUCTION AUDIT
CHECKLIST

This checklist can be used to perform a waste reduction audit at a printed circuit (PC) board manufacturing plant. Plant personnel performing the audit should review the checklist prior to beginning the audit. In addition, Chapter 8 of the report titled Waste Audit Study - Printed Circuit Board Manufacturers, prepared for the California Department of Health Services Alternative Technology Section, describes waste reduction techniques available to PC board manufacturers and provides guidance on how to perform a waste reduction audit.

D1.0 GENERAL INFORMATION

Company Name: ______________________________

Company Address: ______________________________

____

Contact Person: ______________________________

Phone Number: ______________________________

Number of Employees: ______________________________

Hours of Operation Per Day: ______________________________

Square Footage of Board Produced Per Month: ______________

Percentage of Double Sided: ______________

Percentage of Multiple Layer: ______________

(Breakdown by Number of Layers): ______________

D2.0 RAW MATERIAL AND HAZARDOUS WASTE DATA

Fill out tables 2.1 and 2.2 before continuing the checklist. List information on all raw materials used at the plant in Table D2.1. List information on all hazardous waste generated at the plant at Table D2.2. The tabulated information will assist auditors in completing this checklist.

TABLE D2.1
RAW MATERIAL DATA

MATERIALS	SUPPLIER	COST/ UNIT	ANNUAL USAGE	ANNUAL COST	DISPOSAL METHOD
Process Chemicals: o Cleaners					
o Conditioners					
o Catalysts					
o Etchants					
o Plating Chemicals					
o Others					

TABLE D2.1 (continued)
RAW MATERIAL DATA

MATERIALS	SUPPLIER	COST/ UNIT	ANNUAL USAGE	ANNUAL COST	DISPOSAL METHOD
Equipment Cleaning Chemicals: o Nitric Acid					
o Solvents					
o Others					
Wastewater Treatment Chemicals: o pH Adjustors					
o Precipitants					

TABLE D2.1 (continued)
RAW MATERIAL DATA

MATERIALS	SUPPLIER	COST/ UNIT	ANNUAL USAGE	ANNUAL COST	DISPOSAL METHOD
o Coagulants					
o Others					

TABLE D2.2
HAZARDOUS WASTE DATA

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
o Industrial Treatment Sludge				
o Spent Process Baths				
o Equipment Cleaning Solutions				
o Off-Specification Materials				
o Unused Samples				

TABLE D2.2 (continued)
HAZARDOUS WASTE DATA

WASTE	ANNUAL QUANTITY GENERATED	DISPOSAL METHOD	DISPOSAL COST/UNIT	ANNUAL DISPOSAL COSTS
o Spill Clean-up Materials				
o Others				

D3.0 RAW MATERIAL USAGE/HANDLING

Many wastes are generated by degradation of raw materials and by spills. This section is designed to help determine if these waste streams can be reduced.

Are off-specification material wastes generated because the material has exceeded its shelf life? _____ Yes _____ No

How often is an inventory performed to identify an accumulation of materials?

_____

Does the company utilize a first-in first-out material usage policy to prevent materials from being deteriorating in storage? _____ Yes _____ No

Does the company minimize inventory to prevent material degradation due to prolonged storage? _____ Yes _____ No

Does the plant accept samples from chemical suppliers? _____ Yes _____ No

Do unused samples become waste? _____ Yes _____ No

Has a person been designated for approving the acceptance of samples?

_____ Yes _____ No

Are suppliers required to take back unused samples they provide?

_____ Yes _____ No

Does the plant generate wastes due to spills during material handling or storage?

_____ Yes _____ No

If yes, describe the frequency of these spills. ______________________________

How often is the storage area inspected to check the integrity of containers and their proper storage? ______________________________

Are personnel trained to ensure proper handling and storage of materials?

_____ Yes _____ No

Is spill containment provided to minimize the amount of clean-up materials used to contain and clean-up spills? _____ Yes _____ No

Describe spill containment used in material storage areas. ____________________

____

____

____

____

Summary of Raw Material Usage/Handling Waste Reduction Opportunities:

Complete Table D3.1 to identify potential techniques for reducing waste generation associated with raw material storage and handling. Implementation potential should be based on technical constraints and limitations due to the plant's size and layout. Economic limitations will be evaluated in Section 6.0.

TABLE D3.1

SUMMARY OF RAW MATERIAL USAGE/HANDLING WASTE REDUCTION OPPORTUNITIES

Waste Reduction Technique	Currently Used (Yes/No)	Implementation Potential High	Medium	Low	None
Off Spec Materials:					
o Improved Inventory	______	____	______	___	____
o First-in First-out Policy	______	____	______	___	____
o Reduce Quantities Stored	______	____	______	___	____
Unused Samples:					
o Designate Sample Acceptor	______	____	______	___	____
o Return to Suppliers	______	____	______	___	____
Material Spills:					
o Increased Inspections	______	____	______	___	____
o Improved Training	______	____	______	___	____
o Spill Containment	______	____	______	___	____

D4.0 PRODUCTION PROCESSES

Fill out Table D4.1 and D4.2 before continuing the checklist. List information about all rinse systems associated with the process lines in Table D4.1. List information about each process bath in Table D4.2.

D4.1 SOURCE REDUCTION

Material Substitution:

Has the company attempted to replace all chelated process chemistries with non-chelated process chemistries? _____ Yes _____ No

Additional treatment chemicals are often required to breakdown chelators and precipitate metals during wastewater treatment. These chemicals contribute to sludge volume.

Does the plant have access to a Publically Owned Treatment Works (POTW)?
_____ Yes _____ No
Does the POTW have a pretreatment program for industrial waste discharges?
_____ Yes _____ No
Has the company attempted to replace all process bath chemicals that, when spent, are handled as hazardous waste with chemicals that can either be recycled or treated and discharged to the POTW when their process baths become spent?
_____ Yes _____ No

Many chemical manufacturers now provide chemical products that can be returned for recycling or treated on-site in the plant's treatment facility. Examples of these include peroxide/sulfuric etchants, electroless copper baths, reflow oil, and electroplating rack stripper materials.

TABLE D4.1
RINSE SYSTEM INFORMATION

RINSE SYSTEM IDENTIFICATION NUMBER	RINSEWATER FLOWRATE	NUMBER OF TANKS (Yes/No)	COUNTER CURRENT SYSTEM (Yes/No)	PROCESS BATH(S) PRECEEDING RINSE SYSTEM	ESTIMATED DAILY WATER USAGE

TABLE D4.2
PROCESS BATH INFORMATION

PROCESS BATH/ IDENTIFICATION NUMBER	CHEMICAL CONSTITUENTS AND CONCENTRATIONS	PROCESS BATH VOLUME IN TANK	DRAG-OUT VOLUME/ FULL RACK LOAD	METHOD OF DISPOSAL	FREQUENCY OF DUMPS	CONTAINS CHELATORS (Yes/No)

List all process chemistries in Table D4.3 that were identified as containing chelators or require handling as hazardous waste when spent. Contact chemical suppliers to inquire about the availability of non-chelated chemicals or treatable and recyclable chemicals to replace chemicals on the list. Discuss maintenance considerations and the effects on other processes that replacement with these chemistries would entail.

TABLE D4.3

POTENTIAL PROCESS CHEMISTRY REPLACEMENT

Present Chemistries Used	Potential Replacements	Advantage/ Disadvantage

Improved Rinse Efficiency:

Does the plant have the available space to install multiple counter-current rinse tanks at any of the rinsing stations? _____ Yes _____ No

Have the flow rates used on all the rinse systems been determined based on rinsing needs of the particular process chemistry? _____ Yes _____ No

To determine the required rinse water flow rate for each single stage rinse system, use the following equation:

$$*Q = D(Cp/Cr)$$

where
- Q = Rinse water flow rate
- D = Drag-out rate (see drag-out loss reduction in this worksheet for methods to calculate drag-out).
- Cp = Chemical concentration in process bath
- Cr = Allowable chemical concentration in rinse bath

* (Equation taken from EPA report titled Summary Report - Control and Treatment Technology for the Metal Finishing Industry - In - Plant Changes, January 1982.)

To determine the flow rate required to operate multiple stage counter-current rinse systems use the following equation:

$$*Q = [(Cp/Cr)^{1/N} + 1/N]D$$

Where N = number of rinse tanks in the counter-current rinse system.

* (Equation taken from EPA report titled Summary Report - Control and Treatment Technology for the Metal Finishing Industry - In - Plant Changes, January 1982.)

Complete Table D4.4 for all rinse systems used at the plant.

TABLE D4.4

RINSE SYSTEM FLOW RATE DATA

Rinse Tank	Present Water Flow Rate	Required Flow Rate	Multiple Counter-Current Rinse Flow Rate

Does the plant utilize flow restrictors, flow control meters, or other devices intended to regulate the flow of water through all the rinse tanks?

_____ Yes _____ No

Agitation improves rinse efficiency so that less water is needed to do the job. Do all the rinse systems utilize forced air or forced water as a means of agitating the rinse solution? _____ Yes _____ No

If no, are workpiece racks agitated manually while submersed in the rinse solution?

_____ Yes _____ No

Does the sum of each rinse system's estimated daily water usage approximate the average daily volume of wastewater treated? _____ Yes ____ No

If no, rinse water lines are most likely being left on even when the process line is not in operation. Automated flow controls or increased training of personnel in watet conservation should be considered.

Drag-out Reduction:

Drag-out loss of process chemicals is a significant source of waste generation. Process chemical drag-out carried away in the rinse water effluent contributes to sludge volume when the contaminants are removed during industrial waste treatment. In addition, the greater the drag-out volume entering the rinse system, the greater the volume of water required to perform adequate rinsing.

The volume of drag-out from process baths can be calculated by sampling the rinse water solution after a full work piece rack has been rinsed. The rinse tank must not have its water turned on during the sampling, however. The following equation can be used to calculate drag-out:

$$Vd = \frac{(Cr) \times (Vr)}{Cp}$$

Where
- Vd = Volume of drag-out loss
- Vr = Volume of water in the rinse tank
- Cp = Concentration of chemicals in process bath
- Cr = Concentration of chemicals in rinse water

The chemical chosen for analysis in the rinse water sample should be one that (1) can be quantified in the process solution and (2) will not break down in the rinse solution to a level where comparison of the concentration in the rinse with its concentration in the process bath is invalid. The values obtained for drag-out can be used to assess rinse efficiency techniques, drag-out reduction techniques, and resource recovery techniques.

Drag-out can also be measured volumetrically by utilizing a drainage pan to catch all the drag-out that will drain from the circuit boards and the work piece racks. After all free liquid has drained from the work piece rack, the volume of liquid can be measured. Although this method will not allow measurement of the volume of drag-out that forms a thin film on circuit board surface, it can be used to assess effectiveness of slower work piece withdrawal and longer drainage time.

Complete Table D4.5 describing drag-out loss data for each process tank.

TABLE D4.5
DRAG-OUT LOSS RATE DATA

Process Tank	Present Drag-out Rate	Potential Drag-out Minimization Technology Employed

Has an optimal removal rate and drainage time for work piece racks been determined for each process bath? _____ Yes _____ No

Are personnel trained to consistently follow proper work piece rack removal rates and drainage times? _____ Yes _____ No

Are personnel retrained periodically to assure these procedures are followed?
_____ Yes _____ No

Can any of the chemical process baths be operated at a higher temperature without adversely affecting production quality? _____ Yes _____ No
Process baths operated at elevated temperatures will have less drag-out then when operated at room temperature.

Are process baths operated at the lower end of the manufacturers suggested range of operating concentrations? _____ Yes _____ No
Are fresh process bath solutions operated at a lower concentration than replenished process bath solutions? _____ Yes _____ No
The lower the concentration in the process bath, the lower the volume of drag-out loss.

Is there space between process bath tanks and their associated rinse tanks that allows process chemicals to drip onto the floor? _____ Yes _____ No
If yes, drain boards can be used to direct drainage back into the process tank.

Do process baths that operate at elevated temperatures utilize drag-out tanks as the initial rinse following the bath? _____ Yes _____ No
If yes, is the drag-out tank solution added back to the process tank?
_____ Yes _____ No
Has the company studied the possibility of using the drag-out solution for process bath replenishing? _____ Yes _____ No

Cleaning Solution Reduction:

Cleaning solution wastes can be reduced by using multiple stage cleaning systems. Multiple stage cleaning can include any process where several solutions are used to clean equipment. The first solution is used for initial cleaning and is a previously used solution. The proceeding solution can be fresh cleaner. When the first solution becomes too contaminated to adequately perform initial cleaning, it is removed from the cleaning process for disposal. The second solution then becomes the first. This method of equipment cleaning produces significantly less cleaning solution waste. The more cleaning solution stages used, the less volume of solution required for each cleaning stage. Therefore, less waste is generated when the first solution is disposed.

Does the plant utilize multiple stage cleaning lines for all equipment cleaning operations? _____ Yes _____ No

List the equipment cleaning operations used at the plant in Table D4.6 and describe how each has or can incorporate some method of a multiple cleaning line. This can be done by using multiple cleaning tanks or if the cleaning solution is used to clean-out a tank, using multiple cleaning steps with each step using a less contaminated solution.

TABLE D4.6

EQUIPMENT CLEANOUT PROCESS DATA

Cleaning Process	Potential Multiple Stage Cleaning Options

Summary of Source Reduction Opportunities:

Complete Table D4.7 to identify potential source reduction techniques that can be implemented into the plant's production processes. Implementation potential should be based on technical constraints and limitations due to the plant's size and layout. Economic limitations will be evaluated in Section 6.0.

TABLE D4.7

SUMMARY OF SOURCE REDUCTION OPPORTUNITIES

Waste Reduction Technique	Currently Used (Y/N)	Implementation Potential			
		High	Medium	Low	None
o Nonchelated Process Chemistries					
o Treatable or Recyclable Process Chemistries					
o Multiple Rinse Tanks					
o Reduced Rinse Water Flow Rates					
o Flow Restrictors					
o Control Meters					
o Work Piece Rack Agitation					
o Turbulence Agitation					
o Slower Work Piece Removal Rates					
o Longer Work Piece Drainage					
o Elevated Process Bath Temperatures					
o Reduced Process Bath Concentrations					
o Drain Boards					
o Drag-out Tanks					
o Multiple Stage Equipment Cleaning Lines					

D4.2 RECYCLING AND RESOURCE RECOVERY

Does the plant generate rinse water effluents from rinse operations that follow mild and/or strong acid etching and cleaning processes?

_____ Yes _____ No

If yes, are the rinse solutions recycled for use in rinse systems following alkaline cleaning baths? _____ Yes _____ No

Evaluate the potential for recycling the rinse water effluent from each rinse system for reuse as rinse water influent to another rinse system. The most likely candidates would be the effluent from a rinse system following acidic cleaning processes being used as the influent to a rinse system that follows an alkaline cleaning line. Other possibilities include rinse effluent following a mild acid cleaning line used as influent for a system following a strong acid cleaning or etching line. In List required flow rates for each recycling combination of rinse systems in Table D4.8 and determine the need for holding tanks, replumbing, and process line rearrangement.

TABLE D4.8

RINSE WATER RECYCLING DATA

Rinse System Effluent Flow Rate	Rinse System Influent Flow Rate	Other Considerations

Does the plant generate spent alkaline and/or acidic baths that can be used for elementary neutralization in the industrial waste treatment process?

_____ Yes _____ No

Evaluate the potential for reusing spent process baths for other purposes such as elementary neutralization during waste treatment. In Table D4.9 list the acidic or alkaline spent process baths generated and identify a wastewater treatment neutralization process that could use this material. Consult with process chemical and treatment system representatives to evaluate the potential for reusing these spent process baths.

TABLE D4.9

POTENTIAL SPENT ACID/ALKALINE BATH REUSE OPPORTUNITIES

Process Bath/pH/ Volume Per Month	Neutralization Process/pH Volume Per Month

---

Does the plant generate waste streams that contain valuable process chemicals or metals? _____ Yes _____ No

If yes, does the plant currently utilize any recycling technologies to recover valuable process chemicals or metals? _____ Yes _____ No

Recovery unit equipment representatives should be consulted to evaluate the feasibility of using chemical recovery technologies. However, when discussing these technologies with equipment representatives, waste characterization data will be needed. Fill out Table D4.10 to develop the necessary data. Potential recovery technologies include reverse osmosis, ion-exchange, electrolysis, and evaporation.

TABLE D4.10
RESOURCE RECOVERY EQUIPMENT EVALUATION DATA

Waste Source	Chemical Constituents	Chemical Concentration	Waste Flow Rate GPM GPD	Potential Recovery Technologies

---

Does the plant utilize treatment technologies to recycle rinse water?

_____ Yes _____ No

If no, has the plant assessed the potential for developing a closed loop rinse water system? _____ Yes _____ No

Does the plant generate copper sulfate crystals? _____ Yes _____ No

If yes, are the crystals recycled into the copper electroplating solution or treated to recover copper? _____ Yes _____ No

If no, the plant should assess the potential for regenerating copper electroplating baths with copper sulfate crystals generated in the copper etchant baths.

Does the plant use an alkaline stripper to clean photoresist material off of printed circuit boards? _____ Yes _____ No

Is the stripper decanted or filtered periodically to remove polymer flakes and increase the useful life of the stripper? _____ Yes _____ No

---

Summary of Recycling and Reuse Recovery Opportunities:

Complete Table D4.11 to identify potential recycling and resource recovery techniques that can be implemented into the plant's production process. Implementation potential should be based on technical constraints and limitations due to the plant's size and layout. Economic limitations will be evaluated in Section 6.0.

TABLE D4.11

SUMMARY OF RECYCLING AND RESOURCE RECOVERY OPPORTUNITIES

Recycling Recovery Technique	Currently Used (Y/N)	Implementation Potential			
		High	Medium	Low	None
o Rinse water reuse	______	____	______	___	____
o Use of spent alkaline/acidic baths for neutralization	______	____	______	___	____
o Process chemical or metals recovery	______	____	______	___	____
- Reverse osmosis	______	____	______	___	____
- Ion exchange	______	____	______	___	____
- Electrolysis	______	____	______	___	____
- Evaporation	______	____	______	___	____
- Others	______	____	______	___	____
o Rinse water recycling	______	____	______	___	____
o Copper sulfate crystal reuse	______	____	______	___	____
o Photoresist stripper decantation	______	____	______	___	____

D5.0 ALTERNATIVE TREATMENT

Natural non-hazardous contaminants, such as phosphates and carbonates, can contribute to, and thereby expand, the total volume of sludge generated as waste during industrial waste treatment. In addition, these natural contaminants often require greater quantities of rinse water to do the job. Therefore, pretreating process rinse waters can reduce hazardous waste generation and rinse water usage.

Does the plant pretreat water prior to its use in production processes?

_____ Yes _____ No

If no, consult with equipment manufacturers to determine the treatment unit size necessary to treat the water used in various production processes and to identify other considerations necessary to assess the potential for pretreating water. Analysis of an untreated water sample may also provide information necessary to determine the effectiveness of pretreating process water. Process chemical manufacturers may be able to assist auditors in determining potential improvements in production and waste treatment.

Has the plant evaluated the use of alternative treatment chemicals (such as caustic soda instead of lime or polyelectrolytes instead of alum or ferric chloride) to identify those that generate the lowest volume of sludge? ___ Yes ___ No

In Table D5.1 list treatment chemicals presently used in treatment systems and consult with chemical suppliers to identify alternative treatment chemicals that may decrease current sludge volume. Plant may decide to experiment with alternative treatment chemicals and monitor sludge generation.

TABLE D5.1

ALTERNATIVE WASTEWATER TREATMENT CHEMICALS

Chemical Presently Used/Cost	Substitute Chemical/Cost	% Change in Sludge Volume (estimated or observed)

Does the plant use chelators in any of the process baths? _________ Yes _____ No

As stated in Section 4.1 of this checklist, wastestreams that contain chelators often require additional treatment. This additional treatment will cause a greater volume of wastewater treatment sludge to be generated.

Are additional treatment steps, such as adjustment of pH to below 2 or ferrous sulfate reduction required to treat chelated waste streams? _____ Yes _____ No

If yes, are waste streams that contain chelators segregated from other waste streams prior to treatment? _____ Yes _____ No

Are waste streams that only require neutralization segregated from waste streams that require metal removal? _____ Yes _____ No

In Table D5.2 list all separate waste sources that normally are mixed prior to treatment and/or off-site disposal. For each source, auditors should identify what treatment steps are needed before waste can be discharged. Auditors should then evaluate the impact separate treatment of these waste sources will have on waste volume. Mixing of wastewater may interfere with the efficient treatment of separate waste streams and, therefore, cause additional treatment chemicals to be used. This can generate additional wastewater treatment sludge.

TABLE D5.2

WASTE SOURCE SEGREGATION OPPORTUNITIES

Waste Source	Necessary Treatment Prior to Discharge	Potential for Separate Treatment

Is the solids concentration of the industrial waste sludge less than 30%?

____ Yes _____ No

If yes, has the plant considered dewatering sludge to reduce its volume?

____ Yes _____ No

If the solids content of the sludge is above 30 percent, has the plant considered using sludge dryers to further reduce sludge volume? _____ Yes _____ No

Based on the volume and solids concentration of sludge, the auditors should identify the type of dewatering units that are pertinent to their application. Equipment suppliers should be consulted. Fill-in Table D5.3 with the information obtained on sludge dewatering technologies.

TABLE D5.3

SLUDGE DEWATERING DATA

Source of Sludge	Solids Content	Volume Generated Each Month	Applicable Dewatering Technologies

---

Does the plant operate an industrial waste treatment facility?

_____ Yes _____ No

If yes, does the treatment facility produce a wastewater treatment sludge that is handled as a hazardous waste? _____ Yes _____ No

If yes, has the plant evaluated the use of an alternative treatment systems that produce less residual waste than the existing treatment facility?

_____ Yes _____ No

Complete Table D5.4 with available data on the plant's industrial waste streams. After assembling available wastewater characterization data, auditors should consult with equipment manufacturers' representatives to evaluate the feasibility of utilizing alternative wastewater treatment systems that do not generate a sludge residue. Applicable technologies include reverse osmosis and ion-exchange.

TABLE D5.4

ALTERNATIVE TREATMENT TECHNOLOGY DATA

Wastewater Stream	Volume GPM GPD	Chemical Analyses Data	Potential Alternative Treatment	Comments

---

Summary of Alternative Treatment Waste Reduction Opportunities:

Complete Table D5.5 to identify potential alternative treatment techniques that can be implemented by the plant. Implementation potential should be based on technical constraints and limitations due to the plant's size and layout. Economic limitations will be evaluated in Section 6.0.

TABLE D5.5

SUMMARY OF ALTERNATIVE TREATMENT WASTE REDUCTION OPPORTUNITIES

Alternative Treatment Technique	Currently Used (Y/N)	Implementation Potential High	Medium	Low	None
o Process water pretreatment	_____	____	______	___	____
o Alternative treatment chemicals	_____	____	______	___	____
o Waste stream segregation	_____	____	______	___	____
o Sludge dewatering	_____	____	______	___	____
o Alternative wastewater treatment	_____	____	______	___	____

D6.0 ECONOMIC DATA

Complete Table D6.1 before continuing the checklist. Table D6.1 provides space for summarizing economic information on material purchase costs, waste disposal costs, and waste reduction equipment purchase costs. The data listed in the table can then be used by the plant to perform cost benefit analyses on waste reduction opportunities identified during the audit.

Cost/benefit analysis worksheets should be completed for each waste reduction technique identified as having a high, medium or low implementation potential. A copy of the cost/benefit analysis worksheet is provided at the end of this checklist. The worksheet is intended to aid the auditors in developing rough estimates of projected costs, savings, and payback periods associated with each waste reduction technology. They do not take into account amoritization, depreciation, or tax factors.

TABLE D6.1

ECONOMIC DATA SUMMARY SHEET

MATERIALS PURCHASE COSTS

Material	Cost/Unit	Cost/Month
Water Fees Treatment Chemicals		
Process Chemicals		

TABLE D6.1 (continued)
ECONOMIC DATA SUMMARY SHEET

WASTE DISPOSAL COSTS

Waste	Cost/Unit	Cost/Month
Sewer Discharge		
Hazardous Wastes		
- Industrial Treatment Sludge		
- Nitric Acid Waste		
- Photoresist Stripper Waste		
Others		

WASTE REDUCTION EQUIPMENT PURCHASE COSTS

Equipment	Description	Cost
Process Tanks		
Storage Tanks		
Conductivity Meters		
Flow Restrictors		
Plumbing Materials		
Pumps		
- Air		
- Water		
Sludge Dewatering Equipment Material Recycling/Recovery Units		

TABLE D6.1 (continued)

ECONOMIC DATA SUMMARY SHEET

Other Equipment	Description	Cost

TABLE D6.2

COST/BENEFIT ANALYSIS WORKSHEET

WASTE REDUCTION TECHNIQUE:

CAPITAL COSTS

- Equipment	_____
- Installation	_____
- Production Downtime	_____
- Construction Materials	_____
Other	_____
Implementation Costs	_____

ANNUAL OPERATING COST SAVINGS FROM IMPLEMENTATION:

Estimate the material savings that can be achieved by implementing the identified waste reduction techniques. Then using the cost data for these materials calculate the annual savings in material purchases.

Water Use	_____
Sewer Fees	_____
Power	_____
Chemical Usage	
-	_____
-	_____
-	_____
-	_____
-	_____
Waste Handling	
-	_____
-	_____
-	_____
-	_____
-	_____
Labor	_____
Misc.	_____
Total Annual Savings	_____

Does the estimated savings justify an investment in this waste reduction technique? Explain.

APPENDIX E
STATUTES AND REGULATIONS AFFECTING
HAZARDOUS WASTE GENERATORS

CONTENTS

TABLES

APPENDIX E

STATUTES AND REGULATIONS AFFECTING HAZARDOUS WASTE GENERATORS

E.1 Introduction

California generators, transporters and treatment, storage and/or disposal facility operators must comply with laws for handling hazardous materials and wastes. The California Department of Health Services (DHS) is the state agency responsible for controlling and monitoring hazardous waste management. This appendix will discuss some of the federal, state, and local laws, regulations and ordinances that apply to generation, transportation, treatment, storage, and/or disposal of hazardous waste.

Summaries of relevant requirements appear in Tables E-4 and E-5. Persons involved in regulated activities should become familiar with the requirements. If needed, additional help can be obtained from the agencies listed elsewhere in this report. Contact those sources for details and updated information.

E.2 Generator Standards

Article 6, Chapter 30, Division 4, Title 22, California Code of Regulations (CCR) details requirements with which all generators of hazardous waste must ordinarily comply. These requirements include the following:

- Determine if each generated waste is hazardous.

- Obtain an EPA Identification Number.

- Prepare a manifest for all off-site shipments of hazardous waste.

- Prepare and submit biennial reports covering generator activities of the previous year with respect to hazardous waste.

- Comply with requirements for generators who accumulate hazardous wastes outsite, pending off-site shipment within 90 days.

- Ship hazardous wastes off-site within 90 days or obtain a hazardous waste storage facility permit from DHS and comply with other requirements applicable to facility operators.

- Ensure that prior to shipment off-site, all wastes conform with DHS and Department of Transportation regulations for proper packaging, labeling, and marking.

- Pay applicable fees to the California State Board of Equalization for hazardous wastes generated.

The generator is responsible for meeting other requirements that might not be specified in this appendix.

E.2.1 Determination of Waste Classification

The generator of a waste must determine if the waste is hazardous. To do this, the generator must determine if the waste is specifically listed as a hazardous waste (Article 9, CCR), and/or if it is a characteristic hazardous waste (ignitable, corrosive, toxic, reactive) (Article 11, CCR). Certain wastes are also classified as "extremely hazardous wastes." These are listed in Article 9, CCR and their characteristics are identified in Article 11, CCR.

E.2.2 EPA Identification Number

Any generator of hazardous waste must obtain from EPA or DHS an EPA Identification Number. This number must be used on all official documents involving waste generation, transportation, treatment, storage, and/or disposal. This number must also appear on all required reports. A generator shall not offer his hazardous waste to a transporter or to an operator of a treatment, storage, and/or disposal facility who does not have an EPA Identification Number.

E.2.3 Uniform Hazardous Waste Manifest ("Manifest")

A generator who offers for transportation a hazardous waste for treatment, storage and/or disposal off-site must prepare a manifest before shipping the waste off-site. The manifest is a multicopied document that allows the generator and the DHS to track shipments of hazardous waste. The manifest also provides the DHS with data on waste generation throughout the state.

The generator must designate on the manifest one facility which is permitted to handle the waste described on the manifest. A copy of each manifest must be sent to the DHS, and another copy must be maintained by the generator for at least three years.

The manifest includes a waste minimization certification. "Large-Quantity" generators must certify "...that I have a program in place to reduce the volume and toxicity of waste generated to the degree I have determined to be economically practicable...." (This language appears as Item 16 on the Uniform Hazardous Waste Manifest.) "Small-Quantity" generators must certify that they have made good-faith efforts to minimize waste generation. The generator must also certify that he or she has chosen the safest method of treatment, storage, and/or disposal.

E.2.4 Reports

A generator who ships (currently) 5 tons or more of his hazardous waste off-site during the calendar year shall prepare and submit a biennial report to the DHS by March 1 of each even numbered year. The report covers generator activities with respect to hazardous wastes during the previous calendar year. A separate report must be sent annually to the California State Board of Equalization for taxation purposes.

E.2.5 Packaging, Labeling and Marking Requirements for Generators

Hazardous waste must be packaged in accordance with DHS and Department of Transportation (DOT) requirements prior to shipment to a treatment, storage and/or disposal facility. Marking and labeling must also be in accordance with DOT guidelines. A hazardous waste label must be affixed to all hazardous waste containers.

E.3 Recyclable Hazardous Wastes (Recyclable Materials)

If a hazardous waste such as a spent solvent can be recycled and used on-site, it might be exempt from many of the above listed requirements, as well as from DHS permit requirements. The recycling must generally be done continuously without storing the waste prior to reclamation. The recycled material is not considered a waste. Other conditional exemptions for recycling of hazardous waste also exist (Section 25143.2, California Health and Safety Code [CH&SC]).

The DHS' regulations provide a list of recyclable hazardous wastes and suggest methods for recycling them. If a "recyclable" waste is disposed of, the DHS may require the generator to explain why the waste was not recycled. The generator must respond. (See Section 25175, CH&SC and Sections 66763 and 66796, CCR).

E.4 High BTU Wastes

By 1990, any hazardous waste that is to be disposed and that has a heating value greater than 3000 Btu/lb must be incinerated or go through an equivalent treatment process. Also, in 1990, hazardous wastes destined for disposal and containing volatile organic compounds in concentrations exceeding standards to be determined by DHS must be incinerated or be disposed by an equivalent treatment process.

E.5 "Lab Packs"

Most laboratory-generated waste is disposed of in lab packs. Lab packs are steel drums containing small containers of compatible hazardous wastes. The small containers in the drum are packaged in chemical adsorbent. The drum is then sealed and sent to a hazardous waste landfill. As of July 8, 1989 certain waste chemicals in lab packs are restricted from landfills. Most of these are listed in Table E-2.

If a lab pack includes a hazardous waste that contains any of the elements/compounds at or in excess of any of the limits listed in Table E-2, it cannot be disposed on land on and after July 8, 1989.

E.6 Other State and Federal Statutes and Regulations

There are many federal statutes and regulations requiring compliance. Many of these federal laws are the same as California laws. Some of these federal and state laws are discussed below.

E.6.1 Federal Clean Water Act

The Federal Clean Water Act (CWA) mandates the establishment of pretreatment standards for discharges to "publicly owned treatment works" (POTW). Institutions that are connected to public sewers must comply with the CWA pretreatment standards. This could result in not allowing certain compounds down the drain even if diluted (e.g. formaldehyde cannot be discharged to a POTW even in minute quantities with abundant dilution).

The CWA has also established the National Pollutant Discharge Elimination System (NPDES) program which regulates discharges to surface waters. The California State Water Resources Control Board and its 9 regional boards carry out the NPDES program in California.

E.6.2 Federal Occupational Safety and Health Act

The Federal Occupational Safety and Health Act (OSHA) and State occupational safety laws regulate chemical handling on public and private locations. OSHA's "Right-to-Know" provision requires employers to train their employees about hazardous substances they handle. The law applies to paid employees but not necessarily to other individuals. The OSHA "Right-to-Know" provisions (and state "Right-to-Know" laws) have increased the awareness of chemical hazards and they have given impetus to the creation of hazardous waste management programs.

There is currently pending in the California Legislature a bill called the "Student-Right-To-Know" bill which would require educational institutions to develop a safety program for students who handle hazardous materials.

E.6.3 California Proposition 65

Proposition 65 requires private employers to post warnings for persons handling carcinogenic compounds, and restricts all discharges of carcinogenic compounds. This is a new law that at present does not affect public institutions. However, state legislation is pending that will require public institutions to comply.

E.7 Solvent Wastes: Land Disposal Restriction

The 1984 Hazardous and Solid Waste Amendments (HSWA) to RCRA mandated the November 8, 1986 federal restriction on the land disposal of halogenated and non-halogenated solvent wastes. Restricted solvent wastes are numbered F001-F005 as defined in Section 261.31, Title 40, Code of Federal Regulations. On November 7, 1986, EPA announced a conditional extension on the implementation of the restriction. According to the modified restriction, solvent wastes were prohibited from land disposal starting on November 8, 1986, unless one or more of the following conditions applies:

(1) The generator of the solvent waste is a small quantity generator of 100-1000 kg/month of hazardous waste.

(2) The waste contains less than 1 percent total of F001-F005 solvent constituents.

(3) The solvent waste is generated due to cleanup or other remedial action taken under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended.

However, the solvent wastes listed in Items 1 to 3 above are restricted from land disposal effective November 8, 1988.

E.8 Summaries of Pertinent Statutes, Regulations and Ordinances

Table E-5 contains a list of federal, state and local statutes, regulations and ordinances that are relevant to hazardous waste generators. The list includes requirements for raw material handling, waste disposal, air quality control, and discharges to sewers.

E.9 Regulatory Agencies and Information

Appendices G through J identify the regulatory agencies that may be contacted with questions on the management of hazardous wastes. Appendix F has Form DHS 8400 (6/87). This form can be used to obtain copies of California hazardous waste control laws and regulations.

TABLE E-1

RECYCLABLE HAZARDOUS WASTES

- Commercial chemical products including unused laboratory grade products.
- Solvents, used or contaminated, including:
  - Halogenated solvents such as trichloroethane, perchloroethylene, methylene dichloride, chloroform, carbon tetrachloride, and Freons;
  - Oxygenated solvents, such as acetone, methyl ethyl ketone, methanol, ethanol, butanol, and ethyl acetate; and
  - Hydrocarbon solvents, such as hexanes, Stoddard, benzene, toluene, xylenes, and paint thinner.
- Used or unused petroleum products, including motor oils, hydraulic fluids, cutting lubricants, and fortified weed oils.
- Pickling liquor.
- Unspent acids, such as hydrochloric, hydrofluoric, nitric, phosphoric, and sulfuric, in concentrations exceeding 15%.
- Unspent alkalis, including: hydroxides and carbonates of sodium, potassium, and calcium; and acetylene sludge.
- Unrinsed empty containers of iron or steel used for pesticides or other hazardous chemicals:
  - Pesticide containers; and
  - Other hazardous chemical containers.

TABLE E-2

RESTRICTED HAZARDOUS WASTES

Element/Compound	Concentration Limit of Restriction
1. Liquid hazardous wastes containing free cyanides	≥1000 mg/liter
2. Liquid hazardous wastes containing one or more of the following:	
Arsenic and/or arsenic compounds	≥ 500 mg/liter
Cadmium and/or cadmium compounds	≥ 100 mg/liter
Chromium VI and/or chromium VI compounds	≥ 500 mg/liter
Lead and/or lead compounds	≥ 500 mg/liter
Mercury and/or mercury compounds	≥ 20 mg/liter
Nickel and/or nickel compounds	≥ 134 mg/liter
Selenium and/or selenium compounds	≥ 100 mg/liter
Thallium and/or thallium compounds	≥ 130 mg/liter
3. Liquid hazardous wastes with a pH less than or equal to 2.0	-
4. Liquid hazardous wastes containing polychlorinated biphenyls (PCBs)	≥ 50 mg/liter
5. Liquid hazardous wastes containing halogenated organic compounds (i.e. chlorinated solvents)	≥1000 mg/kg

TABLE E-3

SOLVENT-CONTAINING HAZARDOUS WASTES HAVING EPA LAND DISPOSAL RESTRICTIONS

Waste code	Description
F001	The following spent halogenated solvents used in degreasing: tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; spent solvent mixtures/blends used in degreasing containing, before use, a total of 10 percent or more (by volume) of one or more of the above halogen solvents or those solvents listed in F002, F004, and F005; and still bottom from the recovery of these spent solvents and spent solvent mixtures.
F002	The following spent halogenated solvents: tetrachloroethane, chlorobenzene 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, and trichlorofluoromethane; all spent solvent mixture/blends containing before a total of 10 percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F001, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F003	The following spent nonhalogenated solvents: xylene, acetone, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcohol cyclohexanone, and methanol; all spent solvent mixtures/blends containing solely the above spent nonhalogenated solvents; and all spent solvent mixtures/blends containing, before use, one or more of the above nonhalogen solvents, and a total of 10 percent or more (by volume) of one or more of the solvents listed in F001, F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures.
F004	The following spent nonhalogenates solvents: cresols and cresylic acid and nitrobenzene; all spent solvent mixtures/blends containing, before use, a total of 10 percent or more (by volume) of one or more of the above nonhalogenated solvents or those solvents listed in F001, F002, and F005; a still bottoms from the recovery of these spent solvents and spent solvent mixtures.

TABLE E-3 (continued)

Waste code	Description
F005	The following spent nonhalogenated solvents: toluene, methyl ethyl ketone, carbon disulfide, isobutanol, and pyridine; all spent solvent mixtures/blends containing, beofre use, a total of 10 percent or more (by volume) of one or more of the above nonhalogenated solvents or those solvents listed in F001, F002, and F004; and still bottoms from the recovery of these spent solvents and solvent mixtures.

A November 8, 1986 at 40 CFR 268.30(b).

TABLE E-4

SUMMARY OF GENERAL REQUIREMENTS

ACTIVITY	REQUIREMENT	AGENCY
Waste Generation	Shipments of waste must be accompanied by a minifest.	DHS
	Prepare biennial report concerning the volume of waste generated.	DHS
	If wastes are temporarily stored on site, the generator must comply with handling procedures, personnel requirements, etc.	DHS, county hazardous material regulators
	Generators disposing of "recyclable wastes" might be asked to provide justification for not recycling.	DHS
New Process or Process Modification; Material Substitution	If the new process or process modification involves treatment of a hazardous waste, a treatment, storage and/or disposal (TSD) permit might be necessary. In some cases material substitution may constitute process modification.	DHS
	Process must comply with fire codes occupational health requirements.	Local fire department, Cal/OSHA
On-site Treatment	In general, a treatment, storage and/or disposal facility permit is required. DHS may grant variances for activities that are adequately regulated by other agencies or for wastes that are insignificantly hazardous.	DHS
On-site Recycling	Same as above; however, some on-site recycling activities are categorically exempt from permit requirements.	DHS
Off-site Recycling	Commercial (i.e., off-site) recycling activities generally require a TSD permit.	DHS
	Commercial recyclers must submit an annual facility report.	DHS

TABLE E-4 (continued)
SUMMARY OF GENERAL REQUIREMENTS

ACTIVITY	REQUIREMENT	AGENCY
	Some resource recovery facilities are eligible for Series 'A', 'B', or 'C' resource recovery facility permits in lieu of TSD permits.	DHS
Disposal	In California, several classes of hazardous waste are restricted from land disposal.	DHS
	A national land disposal restriction program is being implemented.	EPA
	Disposal facilities must have a TSD permit and comply with technical and financial regulations.	DHS
	Air Pollution	
Industrial	All devices emitting air pollutants must be permitted or exempted.	Local APCD/ AQMD
	If changes in equipment or procedures result in an increase of any pollutant above a specified level, a permit is required.	Local APCD/ AQMD
	If certain designated toxic air contaminants are emitted, the generator must comply with rules established under the toxic air contaminant program.	Local APCD/ AQMD
	If there is an increase in an "attainment pollutant" by a significant amount (generally 25 to 40 tons/yr), a permit may be necessary.	EPA Region IX
	Water Pollution	
Industrial	Discharge of industrial waste to sewer requires a sewer permit.	Local sewer agency
	Discharge of waste to land requires a discharge permit.	Regional Water Quality Control Board
	Discharge of waste to public waters requires an NPDES permit.	Regional Water Quality Control Board

TABLE E-5

SELECTED STATUTES, REGULATIONS AND ORDINANCES RELEVANT TO HAZARDOUS WASTE GENERATION AND MANAGEMENT *

Category	Regulation/Rule	Description
Air quality	SCAQMD Rule 442 SBAQMD Rule 317 MBUAPCD Rule 416 BAAQMD Regulation 8, Rule 35 KCAPCD Rule 410 SLOCAPCD Rule 407 H(1) VAPCD Rule 66	Restrict discharge of organic materials into the atmosphere from equipment in which solvents are used.
	SCAQMD Rule 443	Requires coatings and solvents to be labeled to indicate their photochemical reactivity.
	SCAQMD Rule 1113 SBAQMD Rule 323 MBUAPCD Rule 426 BAAQMD Regulation 8, Rule 3 KCAPCD Rule 410.1 SLOCAPCD Rule 407 H(3)	Establish VOC standards for architectural and specialty architectural coatings.
	SCAQMD Rule 1141.1	Establish operating requirements for coatings and inks manufacturing.
	BAAQMD Regulation 8, Rule 5	Deals with the storage of organic liquids.
	MBUAPCD Rule 429 KCAPCD Rule 413	Deal with organic liquid loading.
	SBAQMD Rule 322 SOLCAPCD Rule 407 H(2)	Prohibit photochemically reactive metal surface coating thinners and reducers.
	SBAQMD Rule 324 KCAPCD Rule 410.2 BAAQMD Regulation 8, Rule 39 SLOCAPCD Rule 407 H(4)	Deal with the disposal and evaporation of solvents.

Category	Regulation/Rule	Description
Solvent storage	CCR Title 23, Chapter 3, Sub-chapter 16	Addresses underground storage of solvents.
	CH&SC Division 20, Chapter 6.7	Regulates underground storage of hazardous substances.
	CCR Title 22, Div. 4, Ch. 30, Article 24	Regulates the use and management of containers.
	CCR Title 22, Division 4, Chapter 30, Article 6	Sets requirements for generators of hazardous wastes including restrictions on how long wastes can be accumulated without the storage facility being permitted.
	CH&SC Section 25123.3	Definition of "storage facility", including quality and time limits for qualification as a storage facility.
	CH&SC Division 20 Chapter 6.95	Requires local government agencies to implement hazardous material management programs requiring local businesses to submit business plans and inventories for the storage and handling of hazardous materials.
	CCR Title 22, Division 4, Chapter 30, Section 66470 to Section 66515	Require generators of hazardous waste to store, label, and manifest hazardous wastes properly.
Hazardous Materials and Wastes	CCR Title 22, Division 4, Chapter 30, Section 66680	Lists specific elements, compounds, and generic materials that are potentially hazardous wastes when they are no longer useful. For example, "solvents" are

Category	Regulation/Rule	Description
		listed as potentially hazardous based on the ignitability criterion.
	40 CFR Part 268	Sets forth federal regulations that restrict the disposal of spent solvents and solvent-containing wastes.
	CCR Title 22, Division 4, Chapter 30, Section 66693 to Section 66723	List the criteria for determining whether a waste is considered hazardous or extremely hazardous, using criteria for ignitability, toxicity, corrosivity, and/or reactivity.
	CH&SC Sec. 25180 to Section 25196	Identify penalties for non-compliance with hazardous waste control laws and regulations.
Wastewater discharge	Clean Water Act 32 U.S.C. 1251 et seq.	Water quality control for waste water disposed in surface waters, municipal sewers, and injection well.
	Safe Drinking Water Act. 40 CFR 141	Water quality control for waste water disposed in surface waters, municipal sewers, and injection well.
	NPDES regulations 40 CFR 122	Regulations on the reduction of pollutant discharges into the waters of the United States.
	CCR Title 23 Subchapter 9	State regulations governing the discharge of waste waters to surface waters. Includes provisions for issuance of permits and setting effluent limitations.
	Local municipal codes addressing discharges to POTWs	Discharge requirements set by local POTWs restricting the concentrations of pollutants in waste waters discharged to sanitary sewers.

Category	Regulation/Rule	Description
Waste treatment, recycling, or disposal	CH&SC Section 25175	Authorizes DHS to provide a listing of recyclable hazardous wastes found by DHS to be economically and technically feasible to recycle. Also authorizes fee penalties for failure to do so, as specified.
	Title 22, CCR Section 66796	List for CH&SC Section 25175 provides a list of recyclable wastes and suggests methods for recycling them.
	Title 22, CCR Section 66763 and CH&SC Section 25175	Specifies method for CH&SC Section 25175 if a "recyclable" hazardous waste is disposed, authorizes DHS to request that the generator explain why the waste was not recycled. The generator must respond. DHS can assess penalties for failure to comply.
	CH&SC, Section 25143.2 (b),(c) and (e)	Exempt recyclable materials from hazardous waste control require- ments if they meet certain conditions.
	CH&SC Section 25180-25196	Specifies penalties for generator non-compliance with the regulations.
	CH&SC Sections 25180-25196	Specifies penalties for facilities with permits, non-compliance with the regulations.
	CH&SC Section 25155.5(a)	Requires incineration or equivalent treatment of hazardous wastes with greater than 3000 Btu/lb. Existing law becomes effective postponed to 1990.

Category	Regulation/Rule	Description
	CH&SC Section 25155.5(b)	Requires incineration or equivalent treatment of hazardous wastes containing volatile organic compounds in concentrations exceeding standards to be determined by DHS. Existing law becomes effective in 1990.
	CH&SC Section 25208.4	Prohibits discharge of any liquid hazardous waste into a surface impoundment located within 1/2 mile of a potential source of drinking water. Contains important exemption provisions.
	CH&SC Section 25202.9	Requires annual certification by hazardous waste generators who operate onsite TSD facilities that they have a waste minimization program in operation. Further, they must certify that the treatment, storage, or disposal methods minimize threats to human health and environment.
	CH&SC Section 25244.4	Requires generators to submit a report every two years on waste reduction status.
	CH&SC Section 25179.6	Would prohibit land disposal of all untreated hazardous wastes with specified exceptions. Effective 1990.
	40 CFR Part 165	Recommended procedures for the disposal and storage of pesticides and pesticide containers.

Category	Regulation/Rule	Description
	32A CFR Part 650	Hazardous and toxic materials management (bibliography and tables).
Land disposal	CH&SC Section 25122.7 and Title 22 CCR Sections 66900-66935	Specifies land disposal restrictions. Lists therein restricted hazardous wastes which include wastes containing more than 1000 mg/kg of halogenated organic compounds.
	40 CFR Section 264.314(b)	Prohibits land disposal of bulk or non-containerized liquid hazardous waste or hazardous waste containing free liquids.
	RCRA Section 3004(e)(1)	Prohibits land disposal of most solvents unless treatment levels (2 ppm for most constituents) are met.
	40 CFR Section 268.3	Prohibits land disposal of dilute waste waters containing solvents and having 1% or less total organics.
	40 CFR Section 265.314 and CCR Title 22, Div. 4, Ch. 30, Sec. 67422	Prohibits land disposal of bulk or non-containerized liquid hazardous wastes or hazardous wastes containing free liquids.
General	40 CFR Part 446	EPA guidelines and standards for Paint formulating industry.

Abbreviations:

APCD - Air Pollution Control District
AQMD - Air Quality Management District
BA - Bay Area
Btu - British thermal unit
CCR - California Code of Regulations
CFR - Code of Federal Regulations
CH&SC- California Health and Safety Code
DHS - Department of Health Services
KC - Kern County
MBU - Monterey Bay Unified
NPDES- National Pollutant Discharge Elimination System
POTW - Publicly Owned Treatment Works
RCRA - Resource Conservation and Recovery Act
SB - Santa Barbara
SC - South Coast
SLOC - San Luis Obispo County
TSD - Treatment, Storage, or Disposal
VOC - Volatile Organic Compounds
V - Ventura

* The generator should contact the appropriate local, state, or federal authority for complete, detailed, and updated regulatory information.

Source: Jacobs Engineering Group, Inc. 1987; and ESE, 1987.