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EPA **ENVIRONMENTAL RESEARCH BRIEF**

Waste Minimization Assessment for a Manufacturer of Printed Circuit Boards

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Abstract

The U.S. Environmental Protection Agency (EPA) has funded a pilot project to assist small- and medium- size manufacturers who want to minimize their generation of hazardous waste but lack the expertise to do so. Waste Minimization Assessment Centers (WMACs) were established at selected universities and procedures were adapted from the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7-88/003, July 1988). The WMAC team at Colorado State University inspected a plant producing printed circuit boards — a plant that already had taken steps to control its hazardous wastes. Producing a circuit board involves many major processes and subprocesses: preparing the board; depositing copper on the board by electroless plating; applying dry film; electrolytically plating copper; electrolytically plating tin; etching and stripping; applying solder; and, perhaps, plating gold on connectors. Each of these steps produces hazardous wastes, e.g., electrolytic copper plating results in acid soap dumps, copper and tin drag-out, and sulfuric acid. The main sources of metallic contamination (copper [both dissolved and metallic], tin, lead, gold) are the rinses after scrubbing, plating, and etching. Although the greatest amount of waste can be reduced by reusing effluent from the MEMTEK † (with some further treatment), the greatest dollar savings can be found by changing the dry film developer. The present brand adheres strongly to the unexposed film and requires an aggressive acid soap; a less aggressive, nonhazardous soap could be used with a less-adhering dry film developer.

This Research Brief was developed by the principal investigators and EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of an ongoing research project that is fully documented in a separate report of the same title available from the authors.

Introduction

The amount of hazardous waste generated by industrial plants has become an increasingly costly problem for manufacturers and an additional stress on the environment. One solution to the problem of hazardous waste is to reduce or eliminate the waste at its source.

University City Science Center (Philadelphia, PA) has begun a pilot project to assist small- and medium- size manufacturers who want to minimize their formation of hazardous waste but lack the inhouse expertise to do so. Under agreement with EPA's Risk Reduction Engineering Laboratory, the Science Center has established three WMACs. This assessment was done by engineering faculty and students at Colorado State University's (Fort Collins) WMAC. The assessment teams have considerable direct experience with process operations in manufacturing plants and also have the knowledge and skills needed to minimize hazardous waste generation.

The waste minimization assessments are done for small- and medium-size manufacturers at no out-of-pocket cost to the client. To qualify for the assessment, each client must fall within

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

Standard Industrial Classification Code 20-39, have gross annual sales not exceeding $50 million, employ no more than 500 persons, and lack inhouse expertise in waste minimization.

The potential benefits of the pilot project include minimization of the amount of waste generated by manufacturers, reduced waste treatment and disposal costs for participating plants, valuable experience for graduate and undergraduate students who participate in the program, and a cleaner environment without more regulations and higher costs for manufacturers.

Methodology of Assessments

The waste minimization assessments require several site visits to each client served. In general, the WMACs follow the procedures outlined in the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7- 88/003, July 1988). The WMAC staff locates the sources of hazardous waste in the plant and identifies the current disposal or treatment methods and their associated costs. They then identify and analyze a variety of ways to reduce or eliminate the waste. Specific measures to achieve that goal are recommended and the essential supporting technological and economic information is developed. Finally, a confidential report that details the WMAC's findings and recommendations (including cost savings, implementation costs, and payback times) is prepared for each client.

Plant Background

This plant typically operates about 4,500 hr/yr to turn out printed circuit boards, which are distributed regionally. Like the plants of some other small and medium-size manufacturers, this one had taken several steps on its own initiative to control hazardous waste emissions. It presented a challenge to the WMAC assessment team in their efforts to identify additional cost-effective measures.

The plant had already taken these kinds of actions to reduce hazardous waste:

- Using dry film photoresist to eliminate chlorinated solvents associated with silk screen application.
- Substituting tin for lead solder after electrolytic copper plating (though a small amount of tin/lead solder is required as a final coating).
- Combining an automated electroless plating machine with countercurrent rinsing to cut down drag-out of plating solution and to reduce the quantity of rinse water.
- Agitating these rinse tanks with compressed air to get better rinsing in a given tank volume.
- Using deionized water in the electrolytic plating lines to lessen the formation of sludge (hard-water deposits).
- Converting to plastic covered racks for those same electrolytic plating lines to reduce (by 75%) the amount of stripping solution needed to remove excess copper and tin deposits on the racks.
- Applying mechanical deburrers, scrubbers, and hot-air dryers to eliminate some hazardous solvents. (The dusts from these operations are collected and sold to a metal reclaimer.)

The basic operation of the plant consists of a complex series of mechanical and chemical process steps to deposit copper selectively on flat sheets of nonconducting materials formed from resins and fiber glass. Of course, the copper must follow certain predetermined patterns dictated by the design of the circuit and the application of the board.

All the quantities of hazardous waste cited here are to be considered in relation to the production level in the plant when these quantities were measured or otherwise established. At the time of the waste minimization assessment, this plant was producing an average of 115 to 120 circuit boards/hr of operation.

Manufacturing Operations

The laminated flat sheets of nonconducting material are first cut to a size slightly larger than the desired end product, then drilled by programed high-speed drills, and finally deburred at the holes and board edges by rotating brushes. A flow chart depicting all the steps in sequence is given in Figure 1.

A thin layer of copper is deposited by electroless plating on boards that are first cleaned and rinsed and then coated with a catalyst for the reduction of the copper. To apply the circuit pattern, a dry film process is used — laminating a photosensitive polymer resist, covering parts of the board with the printed circuit design mask before exposure to ultraviolet light, developing with sodium carbonate, and eventually rinsing with tap water.

Electrolytic plating of copper occurs on the circuit design developed in the preceding series of operations. Then tin is electrolytically plated on the copper to protect the circuit design from the alkaline etchant used to strip away the plating resist. Any copper not protected by tin is also etched away by an alkaline solution. Finally, an ammonium bifluoride-hydrogen peroxide solution removes the tin to complete the electronic circuitry on the board, which is then water-rinsed and air-dried.

The principal remaining step is to apply solder to the desired areas, which are the portions of the boards not coated by an epoxy solder mask, which also functions as an insulator. Then a eutectic solder is coated on the surface not covered by the mask.

To meet certain customers' specifications, connectors are sometimes gold plated before solder mask application.

Hazardous Waste Generation

Most of the hazardous waste generated in this plant occurs in various liquid streams. These major waste streams, together with their treatment, disposal, and recycling costs are given in Table 1.

To put that information into perspective, it is useful to keep in mind that the main sources of metallic contamination are the rinses after scrubbing, plating, and etching.

Dissolved copper occurs in the rinses following etching and plating, in the accelerator and acid activator baths on both plating lines, and in the alkaline etch and rack stripping solutions.

Metallic copper is generated by mechanical cleaning operations, drilling and routing operations, and cutting operations.

Tin comes from electrolytic plating and stripping; lead, from rinsing and deburring.

Rinse streams discharged to the sewer because they are not considered hazardous are those from the dry film developer, the post-clean rinse, the gold plating rinse, and the spent resist stripper.

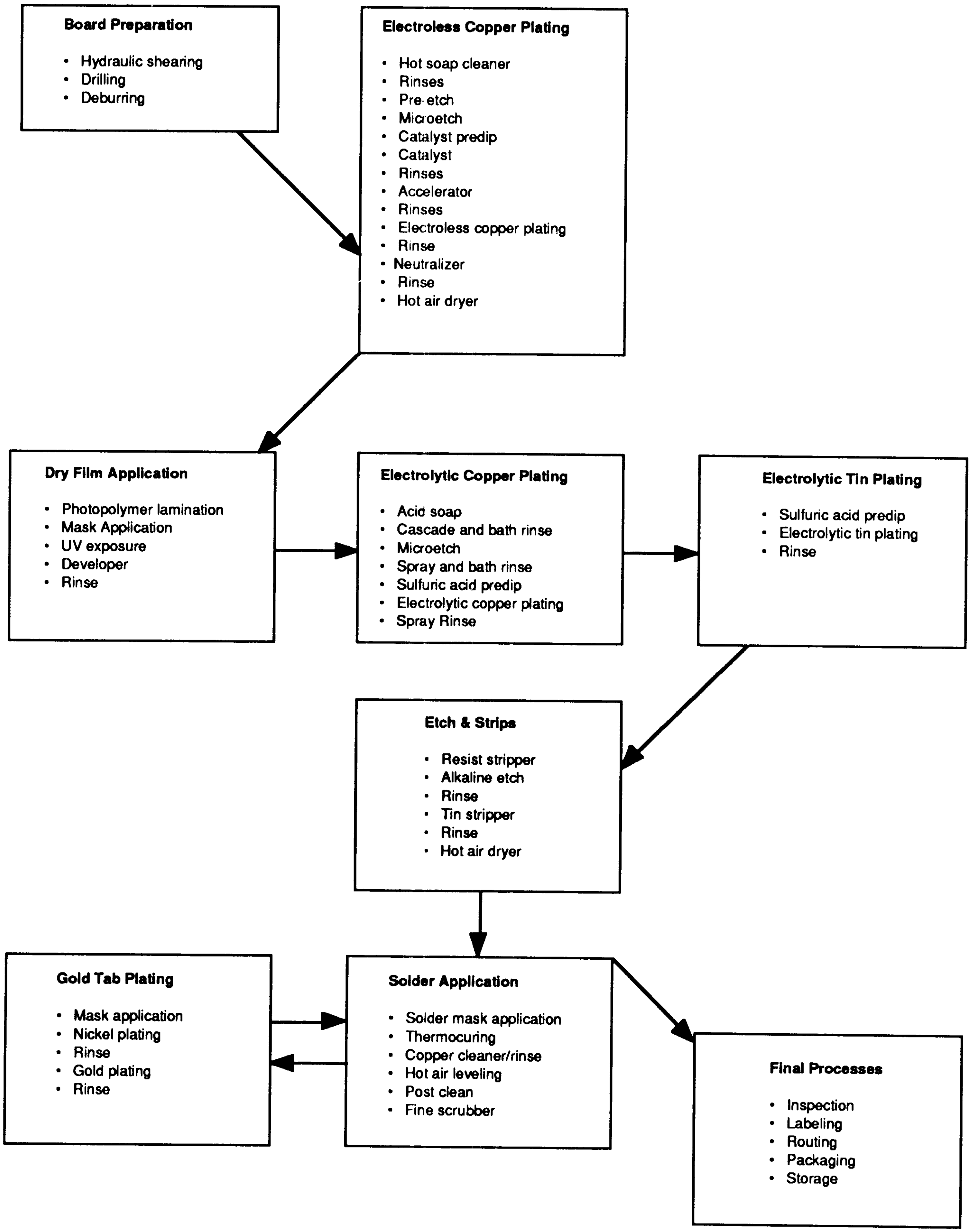

Figure 1. Sequence of Manufacturing Operations.

The other rinses and dumps are directed into a large trench with a level controller (but without a sewer connection). The controller activates a pump to transport the liquids to a MEMTEK ultrafiltration system (to 0.1 μ) that uses chemical reactions, precipitation, and membrane filtration. Suspended solids in an associated concentration tank are removed by bleeding a "slip stream" to a settling tank, from which sludge is dewatered to about 60% solids before it is hauled to a solid disposal site for hazardous wastes.

As noted in Table 1, some solutions are taken out of the plant for metal recovery and a credit.

Summary of Recommended Waste Minimization

Eight waste minimization opportunities (WMOs) recommended by the WMAC team could cut the annual waste management costs at this plant from $86,850 to $42,225, about a 51% reduction. The largest waste volume is liquid (2.97 million gal/yr), but one recommended WMO could reduce that by 62% through recycling effluent from the MEMTEK filtration unit. Because of the relatively low cost of water supply and sewering, however, this large volumetric reduction will save only about $3,840/yr at the present time.

A dry film developer is applied to the circuit boards to remove unexposed photopolymer (under the design mask) and reveal the circuit design. The largest cost saving for a particular WMO ($23,550/yr) is estimated to come from substituting a different developer. The sodium carbonate developer being used requires a very aggressive acid soap to remove it before copper is electrolytically deposited. When this soap is rinsed and the rinsings go to the ultrafiltration unit (MEMTEK), the relatively large soap molecules frequently plug the pores of the filtering membranes in the MEMTEK. With a less adhesive developer, a less aggressive soap solution can be applied, and then the washings can be adjusted for pH and sent directly to the sewer. In addition, the conditioner now used to treat the spent acid soap and rinsings before they go to the MEMTEK can be eliminated. The circuit board manufacturer knew of alternative developers, such as Morton Thiokol's Dynaclean, which reportedly can be cleaned by the MacDermid L5-B that forms a nonhazardous waste. Product names are given to illustrate that such products are commercially available.

All eight WMOs are summarized in Table 2, together with their reductions in emissions and the associated savings and costs. The savings are calculated for each WMO independently, but it is obvious that some are related, so that the results from implementing one can affect the results independently calculated for another.

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Table 1. Summary of Current Waste Generation

Waste Stream	Hazardous Waste Generated	Annual Quantity Generated	Annual Waste Management Costs: Treatment	Disposal	Recycling
Hazardous Liquid Waste					
A. Electroless copper:					
Waste rinses	Copper plating and chemical drag-out	916,663 gal			
Catalyst predip	Table salt/water dumps	530 gal			
Accelerator	Copper-laden, dilute hydrochloric acid	530 gal			
			$10,488	$587	
B. Electrolytic copper:					
Acid soap preclean	Acid soap dumps	10,189 gal			
Water rinses	Soap, etch, copper and tin plating drag-out	366,665 gal			
Copper plating predip	10% Sulfuric acid dumps	3,266 gal			
Tin plating predip	2% Sulfuric acid dumps	3,266 gal			
			$4,380	$246	
C. Resist strip, copper etch, and tin strip:					
Water rinses	Etch, resist and tin strips drag-out	549,997 gal			
Alkaline etch	Spent ammonium hydroxide	13,950 gal			
Tin strip	Spent ammonium bifluoride/peroxide	1,450 gal			
Rack stripper	Spent rack stripper	1,550 gal			
			$6,285	$352	$45,765
D. Other processes:					
Deburrer #1	Copper-laden rinse water	366,665 gal			
Deburrer #2	Copper-, tin/lead-, and gold-laden rinse water	366,665 gal			
Scrubber	Epoxy-, Copper-, and tin/lead-laden rinse water	183,332 gal			
Hot air leveling	Copper-, ferric chloride-, hydrochloric acid-laden rinse	183,332 gal			
			$12,570	$704	
Hazardous Solid Waste					
A. MEMTEK unit	Metal hydroxide sludge	27,700 lb		$5,471	

Table 1. Continued.

Waste Stream	Hazardous Waste Generated	Annual Quantity Generated	Annual Waste Management Costs		
			Treatment	Disposal	Recycling
B. Electroless copper:					
Microetch	Copper sulfate crystals	2,800 lb			
C. Drilling and routing	Copper, aluminum, and gold dust	200 lb			
D. Deburrer #1	Metallic copper	200 lb			
E. Shearing	Copper/epoxy laminate dropoffs	1,200 lb			
F. Filters:					
Electrolytic copper	Nonhazardous filter cake	25 lb			
Post clean	Tin/lead-laden filters	25 lb			
Auto tab plater	Gold-laden resin filter cartridges	25 lb			

Table 2. Summary of Recommended Waste Minimization Opportunities

Present Practice	Proposed Action	Waste Reduction and Associated Savings
All but four rinse streams (dry film developer, post clean, gold plater, spent resist stripper) and process bath dumps go to a common trench and from there to the MEMTEK, in which they are chemically reduced, precipitated, filtered, and settled.	Reuse the MEMTEK effluent to reduce demand for rinse water. To widen the range of possible uses, some further treatment (e.g., ion exchange, adsorption, and filtration) may be needed. Additional storage tanks, pumps, and piping will be required. Saving occurs in lower water demand and sewer charges.	Waste reduction = 1,833,325 gal/yr Cost reduction = $3,840/yr (net) Implementation cost = $22,000 Simple payback = 5.7 yr
The scrubber uses 183,300 gal/yr to rinse particulates from circuit boards—metallic copper, lead, tin, and epoxy. The liquid containing particulates goes to the MEMTEK,from which effluent goes to the sewer.	Filter (in a closed loop system) scrubber liquids to remove hazardous particulates and recycle the water for rinsing the scrubber. Dispose of filter cartridge as solid hazardous waste.	Waste reducion = 183,300 gal/yr Cost reduction = $2,150/yr (net) Implementation cost = $650 Simple payback = 4 mo
Thorough rinsing is mandatory for many operations in this plant. Observation of the plant revealed operators set flow rates for water excessively high.	Install flow reducers or flow meters on the water supply to seven identified manufacturing operations. Waste reduction and cost savings are calculated only for reduced water usage, treatment costs, and sewer costs.	Waste reduction = 440,000 gal/yr Cost reduction = $5,840/yr Implementation cost = $360 Simple payback = less than 1 mo
The particular brand of dry film developer in use adheres so strongly to the unexposed film that an aggressive acid soap is required for removal. This soap presents problems in the MEMTEK and necessitates prior treatment with conditioning agents.	Change to another dry film developer, use a less aggressive soap (also nonhazardous), and discharge the liquid to the sewer after pH adjustment.	Waste reduction = 13,500 gal/yr Cost reduction = $23,550/yr (based on conditioner use alone) Implementation cost = $0 Simple payback = immediate
Tin is stripped away from the electrolytically deposited copper sites that it protects. A solution of ammonium bifluoride and hydrogen peroxide is the stripping agent. The relatively large quantity of washes is sent off-site for treatment and recovery of tin.	Concentrate the tin stripping solution to reduce hauling and treatment costs. Partial freezing will cost less than evaporation. The metal reclaimer has said the concentrate is acceptable, and there will be no increase in unit costs of hauling and recycling. The separated solid can be melted and sewered.	Waste reduction = 1,650 gal/yr Cost reduction = $4,030/yr (net) Implementation cost = $10,000 Simple payback = 2.5 yr
Deionized water is used for rinsing on the electrolytic copper and tin plating lines. Its use should be extended to the electroless copper plating line.	Use deionized water in five baths in the electroless copper plating line, thereby reducing sludge formation and extending the lifetime of the bath. The savings will be achieved in lower cost of treatment chemicals, as well as in lower water and sewer costs. Use an ion-exchange regeneration system.	Waste reduction = 1,015 gal/yr Cost reduction = $1,840/yr Ion-exchange saving = $6,500/yr Implementation cost = $9,800 Simple payback = 1.2 yr

Table 2. Continued.

Present Practice	Proposed Action	Waste Reduction and Associated Savings
Solid copper waste is collected from the deburrer and copper sulfate from the micro-etch solution.	Improve the collection of copper and send the copper sulfate for recovery instead of storing it.	Waste reduction = 3,200 lb/yr Cost reduction = $700/yr Implementation cost = $0 Simple payback = immediate
Plant operators hold drip racks over certain baths to reduce the quantities of dragout. Times and drainage vary widely.	Install drip racks over the electrolytic plating baths, the acid soap bath, and the micro-etch bath. Lowered consumption of plating reagents, copper nuggets, and tin anodes will result.	Waste reduction = 10 gal/yr Cost reduction = $275/yr Implementation cost = $200 Simple payback = 9 mo

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