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ENVIRONMENTAL RESEARCH BRIEF

Pollution Prevention Assessment for a Printed Circuit Board Plant

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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 waste but who lack the expertise to do so. In an effort to assist these manufacturers 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). That document has been superseded by the Facility Pollution Prevention Guide (EPA/600/R-92/088, May 1992). The WMAC team at Colorado State University performed an assessment at a plant that manufactures printed circuit boards. Templates for the circuit design are generated from customer-supplied circuit information. Copper/epoxy laminates and copper foil are cut into blank boards and layers. Circuit patterns are generated through a series of photolithographic and plating processes. The team's report, detailing findings and recommendations, indicated that the onsite ion-exchange treatment of metal-containing rinse water generates regenerant solutions that could be further treated by electrowinning to recover metals and to achieve significant cost savings.

This Research Brief was developed by the principal investigators and EPA's National Risk Management Research 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 University City Science Center.

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Introduction

The amount of 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 waste generation 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 generation of waste but who lack the in-house expertise to do so. Under agreement with EPA's National Risk Management Research 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 waste generation.

The pollution prevention opportunity 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 Standard Industrial Classification Code 20-39, have gross annual sales not exceeding $75 million, employ no more than 500 persons, and lack in-house expertise in pollution prevention.

The potential benefits of the pilot project include minimization of the amount of waste generated by manufacturers, and reduction of waste treatment and disposal costs for participating plants. In addition, the project provides 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 pollution prevention opportunity 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 locate the sources of waste in the plant and identify 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 manufactures printed circuit boards. It operates approximately 4700 hr/yr to produce about 100,000 ft^2 of product annually.

Manufacturing Process

The plant, which functions as a job- and small-production-shop, produces single-sided, double-sided, and multi-layer circuit boards.

Circuit information is received from customers as blueprints, films, computer diskettes, or computer-generated artwork. Circuit information that is received as artwork is digitized and computer-stored. The template for the circuit design, known as the working film, is laser-generated from the customer's circuit information. Programs that provide drilling instructions for the computer-controlled drilling machines are generated digitally.

The raw materials for printed circuit boards include copper/epoxy laminates and copper foil. Laminates and foil are cut into blank boards and layers using hydraulic shears. Component holes are then generated in the blank boards using high-speed, numerically-controlled drilling machines. The drilled boards are mechanically scrubbed in preparation for plating.

Circuit patterns are created on the individual layers of multi-layer boards with dry-film, positive-image photoresist. The first step in transferring the electrical circuit design to the individual layers is laminating a UV-sensitive dry-film photoresist to the layers. An image of the design is generated by placing a template of the circuit over the film and exposing the film to UV light. Exposed film is polymerized and protects the underlying copper circuitry and unexposed photoresist is removed with an aqueous developing solution and rinse. Unwanted copper is then removed with an ammonia/hydrogen peroxide etchant. The remaining protective film is removed with an alkaline resist stripper leaving the desired copper circuitry. Fiberglass weave sheets impregnated with resin are placed between each layer, and the array is heated and bonded in a hydraulic press. Component holes are then drilled in the multi-layer panels, and the holes are cleaned with a sulfuric acid-based de-smear solution. Further processing of multi-layer boards is identical to that of single and double-sided boards.

The circuit patterns for single and double-sided boards, and the outer layers of the multi-layer boards are generated by a series of photolithographic and plating processes. First, the surfaces are copper-plated in an electroless plating process. This process deposits copper on all exposed surfaces, including the surfaces of drilled holes. Photoresist is then laminated to the board surfaces. Additional copper is electrolytically plated on the surface circuit patterns. After cleaning, the pattern is electrolytically plated with tin/lead solder to protect the copper circuity during subsequent steps to remove the resist film and unwanted copper. The tin/lead layer is removed following resist stripping and copper etching. A solder mask is silk-screened and thermally cured to the board surfaces prior to dipping the boards in molten tin/lead solder. The solder layer provides the customer with a surface for mounting electrical components. Additional processing involves conditioning of the soldered surfaces, cleaning, rinsing, and inspecting the finished circuit boards. Final processing includes silk-screen application of a legend, routing, rinsing, electrical testing, inspections, packaging, and shipping.

An abbreviated process flow diagram for the production of printed circuit boards is shown in Figure 1.

Existing Waste Management Practices

This plant already has implemented the following techniques to manage and mint flowing rinses.

Pollution Prevention Opportunities

The type of waste currently generated by the plant, the source of the waste, the waste management method, the quantity of the waste, and the waste management cost for each waste stream identified are given in Table 1.

Table 2 shows the opportunities for pollution prevention that the WMAC team recommended for the plant. The opportunity, the type of waste, the possible waste reduction and associated savings, and the implementation cost along with the simple payback time are given in the table. The quantities of waste currently generated by the plant and possible waste reduction depend on the production level of the plant. All values should be considered in that context.

It should be noted that the economic savings of the opportunities, in most cases, results from reduction in raw material and costs associated with waste treatment and disposal. Other savings not quantifiable by this study include a wide variety of possible future costs related to changing emissions standards, liability, and employee health. It also should be noted that the savings given for each opportunity that pollution prevention opportunity alone and do not reflect duplication of savings that may result when the opportunities are implemented in a package.

This research brief summarizes a part of the work done under Cooperative Agreement No. CR-819557 by the University City Science Center under the sponsorship of the U. S. Environmental Protection Agency. The EPA Project Officer was **Emma Lou George**.

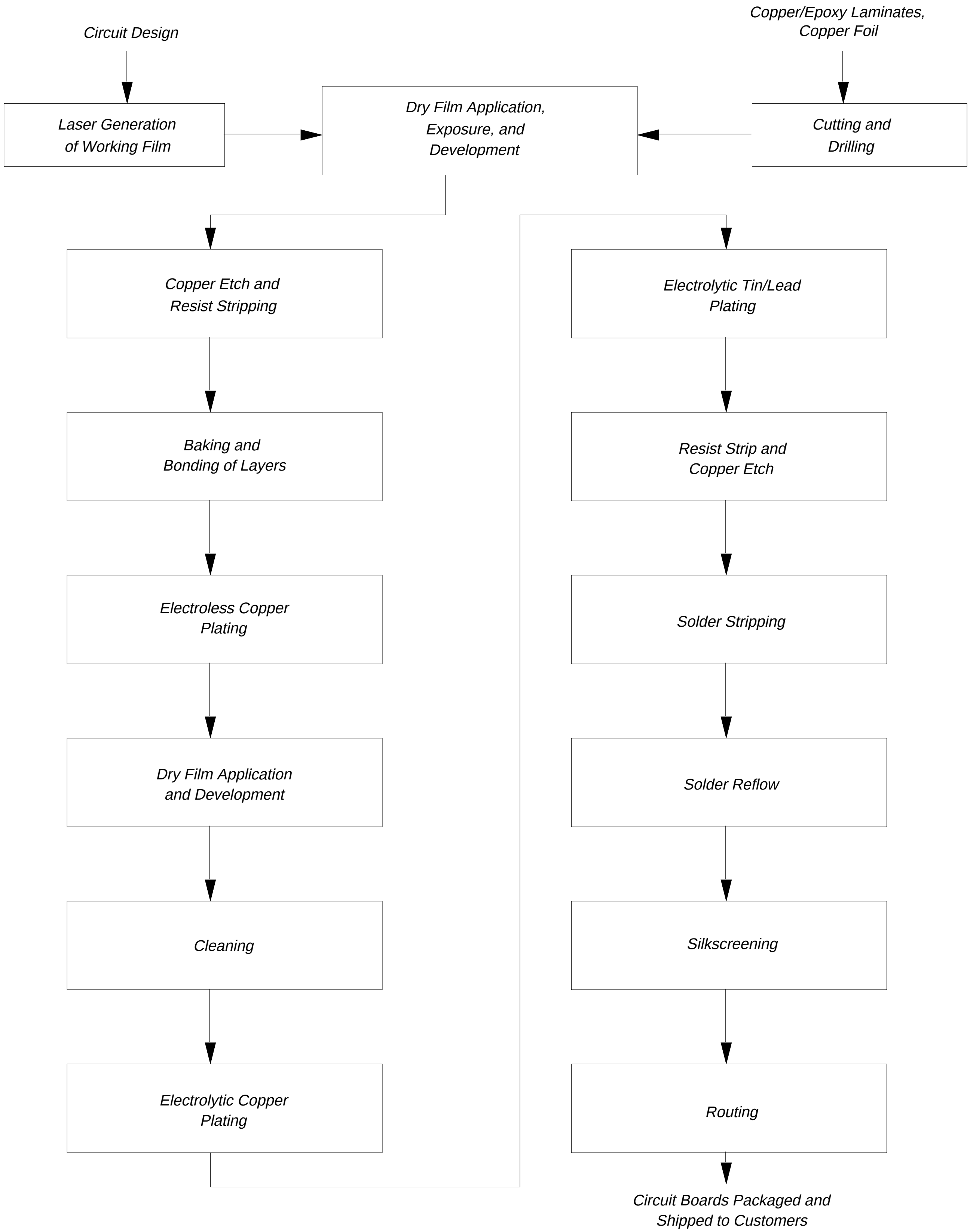

Figure1. *Abbreviated process flow diagram for circuit board production.*

Table 1. *Summary of Current Waste Generation*

Waste Stream Generated	Source of Waste	Waste Management Method	Annual Quantity Generated (lb/yr)	Annual Waste Management Cost
De-smear solution	Electroless copper plating	Shipped off-site as hazardous waste for recovery or disposal	2,290	$2,120
Conditioner solution	Electroless copper plating	Shipped off-site as hazardous waste fo recovery or disposal	2,290	4,050
Pre-dip solution	Electroless copper plating	Shipped off-site as hazardous waste for recovery or disposal	15,580	2,710
Microetch solution (copper sulfate solution)	Electroless copper plating	Shipped off-site as hazardous waste for recovery or disposal	5,500	1,490
Microetch solution (copper sulfate crystals)	Electroless copper plating	Shipped off-site as hazardous waste for recovery or disposal	2,750	470
Rinse water	Electroless copper plating	Treated in on-site ion-exchange columns; sewered	19,364,000	5,740
Organic cleaner	Electrolytic copper plating	Shipped off-site for incineration	11,910	10,060
Copper plating solution	Electrolytic copper plating	Shipped off-site for copper recovery	3,210	6,070
Rinse water	Electrolytic copper plating	Treated in on-site ion-exchange columns; sewered	19,364,000	5,740
Pre-dip solution	Electrolytic tin/lead plating	Shipped off-site as hazardous waste for recovery or disposal	7,330	1,000
Rinse water	Electrolytic tin/lead plating	Treated in on-site ion-exchange columns; sewered	9,682,000	2,870
Copper etchant	Copper etching	Shipped off-site for copper recovery	24,740	17,530
Tin/lead stripper	Solder stripping	Shipped off-site for tin and lead recovery	4,120	6,860
Solder brightener/conditioner	Solder reflow	Shipped off-site as hazardous waste for recovery or disposal	5,040	2,490
Copper regenerant solution	Ion-exchange treatment	Shipped off-site for copper recovery	20,620	6,260
Copper precipitate	Ion-exchange treatment	Shipped off-site for copper recovery	8,250	3,430
Tin/lead regenerant solution	Ion-exchange treatment	Shipped off-site for tin/lead recovery	6,870	2,080
Screen washing solution	Cleaning of silk screens	Shipped off-site for incineration	1,170	2,920
Rack stripping solution	Stripping of racks	Shipped off-site for copper recovery	11,910	3,130
Copper scrap	Board trimming	Shipped off-site as municipal trash	4,520	0

Table 2. *Summary of Recommended Pollution Prevention Opportunities*

Pollution Prevention Opportunity	Waste Stream Reduced	Annual Waste Reduction		Net Annual Savings	Implementation Cost	Simple Payback (yr)
		Quantity (lb/yr)	Per Cent			
Install an electrowinning system in conjunction with the ion-exchange systems on the copper-bearing and tin/lead-bearing rinse water streams to recover dissolved metals from the regenerant solutions. Sell the recovered metals to a recycler. A total of 309 lb/yr of scrap metal will be shipped to the recycler.	Copper regenerant solution Tin/lead regenerant solution	20,620 6,870	100 100	$ 6,640	$ 24,360	3.7
Use polyethylene plating racks in the electrolytic copper plating bath to reduce the need for subsequent stripping of unwanted copper from the metal plating racks.	Rack stripping solution	8,910	75	2,350	4,030	1.7
Install flow meters, flow reducers, and contact switches to reduce water usage by process rinses.	Rinse water (electroless copper plating) Rinse water (electrolytic copper plating) Rinse water (electrolytic tin/lead plating)	2,904,600 2,904,600 1,452,300	15 15 15	2,150	2,560	1.2

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