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ENVIRONMENTAL RESEARCH BRIEF

Waste Minimization Assessment for a Manufacturer Producing 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 waste but who 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 performed an assessment at a plant which manufactures single-sided, double-sided, and multilayer printed circuit boards — approximately 259,000 sq ft/yr. In general, circuit art work is received and digitized. The circuit design film template is laser generated from the digitized artwork. In addition copper/epoxy laminates and copper foil (the inner layer's material for multilayer boards) are cut into blank boards and layers with hydraulic shears. Component holes are cut by drilling machines. Drilled boards are mechanically scrubbed to prepare for plating. Circuit patterns are created on the boards and foil layers with a dry-film photoresist process and the multilayer boards are built up. The actual copper circuit pattern is generated by a series of photolithographic and plating processes. Final processing includes legend application, routing, rinsing, electrical testing, inspections, packing, and shipping. The team's report, detailing findings and recommendations, indicated that the majority of waste was generated in the plating lines and that the greatest savings could be obtained by installing a spray rinse and electrowinning system on the first rinse tank of the electrolytic copper plating line to reduce both copper plating rinse water (88%) and plating sludge (80%) due to drag-out in the first rinse tank.

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 University City Science Center.

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 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 waste but who 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 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 Standard Industrial Classification Code 20-39, have gross annual sales not exceeding $75 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, and reduced waste treatment and disposal costs for participating

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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 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 locate the sources of 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

The plant produces single and multilayer printed circuit boards. The plant operates 4,100 hr/yr to produce approximately 259,000 sq ft of printed circuit board.

Manufacturing Process

This plant manufactures single-layer and multilayer printed circuit boards. Raw materials for board production include copper/epoxy laminates and copper foil. Process raw materials include both dry-film and positive-image photoresist, copper etchant, black oxide reagents, B-stage resin, copper plating reagents, tin plating reagents, photodeveloper, photofixer, stripping and etching solutions, tin/lead solder, and gold-tab plating reagents.

The following steps are involved in making the boards:

- Circuit information is received from customers as blueprints, films, computer floppy diskettes, or some combination of these. Circuit information received as artwork is digitized and stored in a computer. Working film, a template for the circuit design, is laser generated from the customer's circuit information.
- Laminates and foil are cut into blank boards and layers with hydraulic shears. Component holes are then generated in the blank boards with high-speed, numerically-controlled drilling machines. Drill programs are generated digitally and provide drilling instructions for the drilling machines. Drilled boards are mechanically scrubbed to prepare for plating.
- Circuit patterns are created on the board and layers with dry-film photoresist. For the individual inner layers of the multilayer boards, the circuit pattern is generated with positive-image photoresist. The electrical circuit design is transferred to the individual layers by first 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, exposing the film to UV light, and developing the photoresist. Unexposed photoresist is removed, but exposed film is polymerized and protects the underlaying copper circuitry. Unwanted copper is removed with an ammonia etchant. The remaining protective film is removed, and exposed copper circuitry is oxidized and cleaned. Oxidation assures good interlayer bonding between panels in the multilayer array. 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 multilayer panels. Further processing of multilayer boards is identical to that of single and double-sided boards.
- The circuit pattern is 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 plated with tin to protect the copper circuitry during subsequent steps to remove the resist film and unwanted copper. The tin 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 a surface for mounting electrical components. Additional processing involves conditioning of the soldered surfaces, cleaning, rinsing, and inspecting the finished circuit boards. Connector tabs can be gold plated in subsequent processes if requested by the customer.
- Final processing includes silk-screen application of a legend, routing, rinsing, electrical testing, quality assurance inspections, packing, and shipping.

An abbreviated process flow diagram is shown in Figure 1.

Existing Waste Management Practices

This plant already has implemented the following techniques to manage and minimize its wastes:

- Tin plating is used to provide a protective mask for the circuit image during photoresist stripping and copper etching. Unalloyed tin plating replaces traditional tin/lead solder, thereby reducing lead contamination. Tin/lead solder is still used as a final circuit coating.
- Bright tin plating has been replaced by matte tin plating. The matte tin is less dense and provides a greater topography than the bright tin. Thus, the matte tin requires less tin stripper and generates less spent tin stripper.
- Dry film used as plating resist eliminates chlorinated solvents frequently used in silkscreening operations. Silkscreening is still used to apply wet resist solder masks and circuit legends.
- Deburrers and scrubbers using water replace more traditional solvent-based drying.
- The water supply to the electroless copper plating, electrolytic copper plating, black oxide, and gold tab plating lines has been divided so that each line has a separate supply valve. In the past, the water supply to all of these lines was controlled by one valve. By separating the water supply, less water is wasted when a given line is not in use.
- Counterflow rinses and flow reducers are used in plating operations to reduce rinse water usage. Still drag-out tanks are used following electrolytic copper and tin plating to reduce contamination of subsequent flowing rinses.
- An automated plating machine is used on the electroless copper plating line. Automation reduces excess rinse water contamination by providing consistent residence and drainage times.
- Loss of gold in rinse water has been reduced with an ion exchange resin on the gold plating rinse.

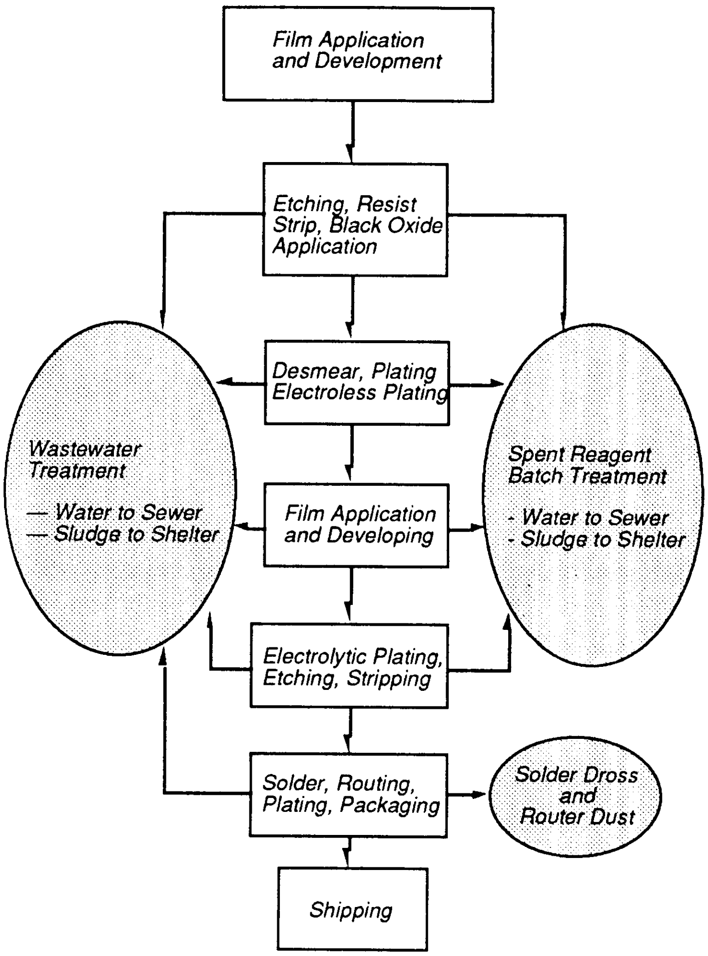

Figure 1. Abbreviated process flow diagram.

- Scrap gold, solder, and aluminum are shipped offsite for recycling.

Waste Minimization Opportunities

The type of waste currently generated by the plant, the source of the waste, the quantity of the waste, and the annual management costs are given in Table 1.

Table 2 shows the opportunities for waste minimization that the WMAC team recommended for the plant. The type of waste, the minimization opportunity, the possible waste reduction and associated savings, and the implementation cost along with the payback times 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, in most cases, the economic savings of the minimization opportunities result from the need for less raw material and from reduced present and future 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 should also be noted that the savings given for each opportunity reflect the savings achievable when implementing each waste minimization opportunity independently and do not reflect duplication of savings that would result when the opportunities are implemented in a package.

This research brief summarizes a part of the work done under Cooperative Agreement No. CR-814903 by the University City Science Center under the sponsorship of the U.S. Environmental Protection Agency. The EPA Project Officer was Emma Lou George.

Table 1. Summary of Current Waste Generation

Waste Generated	*Source of Waste*	*Annual Quantity Generated*	*Annual Waste Management Cost*
Cuposit reagents	*Electroless copper plating line*	*22,050 gal*	*$ 3,714*
Cuposit rinse water	*Electroless copper plating line*	*1,117,200 gal*	*9,354*
Oxide/desmear reagents	*Black oxide/desmear line*	*38,963 gal*	*6,563*
Oxide/desmear rinse water	*Black oxide/desmear line*	*705,600 gal*	*5,908*
Copper plating reagents	*Electrolytic copper and electrolytic tin plating line*	*108,800 gal*	*47,420*
Copper plating rinse water	*Electrolytic copper and electrolytic tin plating line*	*3,823,470 gal*	*37,361*
Spent copper etchant	*Enclosed closed-loop etching machine on the electrolytic copper and electrolytic tin plating*	*22,330 gal*	*88,813*
Spent tin stripper	*Two-step tin removal tanks on the electrolytic copper and electrolytic tin plating*	*5,795 gal*	*81,024*
Gold-tab reagents	*Gold-tab plating line*	*765 gal*	*129*
Gold-tab rinse water	*Gold-tab plating line*	*3,034,080 gal*	*11,804*
Spent nickel plating solution	*Gold-tab plating line*	*165 gal*	*570*
Spent solvent (TCA)	*Gold-tab plating line (to remove masking tape adhesive residue during warm/humid weather)*	*110 gal*	*980*
Press cooling water	*Multilayer circuit board press*	*282,240 gal*	*893*
Developer rinse water	*Photoresist developer rinse*	*1,128,960 gal*	*3,572*
Waste photo fixer	*Photoresist and film developing*	*30 gal*	*0*[1]
Spent rack stripper	*Rack stripping operation*	*1,348 gal*	*22,326*
Plating sludge	*All plating lines*	*116,900 lb*	*24,257*
Copper scrap (dropoffs)	*Circuit board routing and shearing operations*	*8,575 lb*	*0*[2]
Solder dross	*Hot-air leveling*	*6,500 lb*	*23,230*

[1] *Plant personnel report no incremental cost associated with present disposal to POTW.*

[2] *Plant personnel report no incremental cost associated with present disposal in municipal waste.*

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Table 2. Summary of Recommended Waste Minimization Opportunities

Waste Generated	Minimization Opportunity	Annual Waste Reduction Quantity	Annual Waste Reduction Percent	Net Annual Savings	Implementation Costs	Payback Years
Spent rack stripper	Use polyethylene plating racks in the electrolytic copper plating bath to reduce the need for stripping solution.	1018 gal	75.5	$16,951	$28,300	1.7
Plating sludge [1]		448 lb	75.5			
Copper plating rinse water	Install a spray rinse and electrowinning-system to replace the first rinse in the electrolytic copper plating line.	328,300 gal	88	14,453 [4]	17,433	1.2
Plating sludge [2]		14,240 lb	80			
Plating sludge [3]	Increase drain times over the electrolytic copper plating tanks to reduce drag-out.	4,450 lb	25	12,237	1,000	0.08
Oxide/desmear rinse water	Install contact switches on the rinses in the desmear/etchback line to reduce water consumption.	183,750 gal	69	581	645	1.1

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[1] Plating sludge results from treatment of spent stripper.

[2] Plating sludge results from drag-out on first electrolytic copper plating line rinse tank.

[3] Plating sludge results from drag-out on electrolytic copper plating line.

[4] This figure includes copper recycling credit, increased electricity consumption, and cathode replacement cost.

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