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ENVIRONMENTAL RESEARCH BRIEF

Waste Minimization Assessment for a Printed Circuit Board Manufacturer

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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 the University of Tennessee performed an assessment at a plant manufacturing printed circuit boards for television sets—approximately 4.3 million sq ft of finished boards per yr. To make printed circuit boards, the plant begins with making screens as all printing is accomplished using silk-screening techniques. The circuit boards undergo several operations including punching, scrubbing, printing, etching, and soldering. Finished boards are inspected, deslugged, electrically tested, packed, and shipped. The team's report, detailing findings and recommendations, indicated that the majority of waste was generated in the circuit board production lines but that the greatest savings could be obtained by installing a closed-loop cooling water system to reduce (60%) excess water usage in the UV-light curing ovens after screen printing and the cooling of the cupric chloride etch tanks.

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, which is available from the authors.

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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 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 in-house 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 the University of Tennessee's (Knoxville) 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 $50 million, employ no more than 500 persons, and lack in-house 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 proce-

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dures outlined in the EPA *Waste Minimization Opportunity Assessment Manual* (EPA/625/7-88/003, July 1988). The WMAC staff locates 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 detailing WMAC's findings and recommendations (including cost savings, implementation costs, and payback times) is prepared for each client.

Plant Background

The plant produces printed circuit boards for use in television sets. The plant operates 5,760 hr/yr to produce approximately 4.3 million sq ft of finished boards.

Manufacturing Process

The various manufacturing processes used in this plant, along with the wastes that are generated, are described below.

Screen Production

Screens, which are used to transfer ink patterns to the circuit boards, are produced using photographic film sheets, Kodak developer, glue, methyl ethyl ketone (MEK), polyester mesh fabric, screen emulsion, and tape.

Designs for the circuit boards are transmitted from corporate headquarters via modem to the plant's computer system. A laser printer prints the pattern on film sheets to 0.7 millimeter accuracy. The film sheets are developed in a Kodak developing solution and manually water rinsed. Spent water and developer are dumped into the sewer.

In a separate operation, polyester mesh fabric is pneumatically stretched over and glued onto metal frames using screen glue thinned by MEK. Next, emulsion is manually spread onto the screen and allowed to dry for one hour.

The film sheet is then manually taped to the screen, and the unit is exposed to ultraviolet light to transfer the film pattern to the emulsion coating. A water rinse removes the exposed emulsion, leaving the inverse of the circuit pattern on the screen. The emulsion is then electrically heat-cured in an oven for approximately 8 hr at 100°F. Finished screens are stored or transferred to production as needed. The screen production process is illustrated in Figure 1.

Circuit Board Production

Raw materials for this process include pre-sized zinc/copper coated fiberglass panels and screen-printing inks. Operations occur on two separate production lines that are identical except for their capacities.

Six to ten reference holes are initially punched into the panels for alignment purposes. A conveyor then transports the panels to a mechanical wet scrubbing operation that uses nylon brushes and spray-rinsing to remove a protective zinc layer from the copper coating. (The zinc coating prevents oxidation of the copper during shipment to the plant.) Rinse water containing zinc, copper, and brush particles is filtered before being pumped to the plant's water treatment system. Paper filters containing copper, zinc, and brush particles are disposed of in a local landfill. Panels are then dried in a hot-air electric dryer at 130°F.

The panels are stacked and manually transported to one of three screen-printing machines where they are printed with etch resist ink. The etch resist ink prevents the etchant from removing the copper on the board that will form the circuit pattern. The panels are visually inspected and continue to the etching process that is described on page 4. Any rejected panels are processed through the stripping etch resist tank (described in the etching process) and reprinted with the etch resist ink.

After etching, the panels are screen printed with a solder mask ink, then cured in a UV oven at 300°F. This mask prevents the solder or "SealBrite" from adhering to undesired areas. Panels are then screen printed with a legend in white ink on top of the solder mask to identify the board type. After UV curing at 300°F, the panels are screen printed with legend in black ink on the under side of the board to identify circuit components. This ink is also UV cured at 300°F. Panels are then air cooled, stacked, and allowed to stabilize dimensionally for 8 hr until their temperature reaches 85°F.

Waste ink from all four screen-printing operations (etch resist, solder mask, white legend, and black legend) is scraped off screens and machines and is reused. A xylene/propylene special-blend solvent is used for cleaning screens and machines. Rags containing waste ink and solvent from the four screen-printing operations are recycled offsite. Broken screens are landfilled without cleaning, and screens that are still intact but no longer needed are cleaned and recycled. The UV ovens on all four screen-printing operations are maintained at 300°F via cooling water.

After air cooling, the panels undergo punching and solder or SealBrite coating operations. Panels with boards that will not support surface-mounted components (approximately 10% of the product) undergo the micro-etch and solder coating as described in a separate section. Those panels are then processed through a two-stage punching operation. In the first stage, 1,500-2,000 holes per board are punched into the panels for component wiring. (Each panel contains two to eight boards, depending on finished board size and original panel size.) In the second stage, called compound punching, the final wiring holes are punched and the panels are cut into their respective boards. Alignment for these punching operations is accomplished by a printed bar code on the board (provided by the legend printing process), which is read by the punching machine. Panel webbing and slugs, amounting to 13% of the original panel area, are hauled to a local landfill. Boards are then stacked and ready for inspection.

All panels with boards that have surface-mounted components (90% of product) undergo two-stage punching operations exactly as described above but on different machines. Panel webbing and slugs are hauled to a landfill. Individual boards are then transferred to the micro-etch and SealBrite coating process described in a separate process description. After SealBrite coating, boards are stacked and ready for inspection.

All finished boards are visually inspected. About 4% of the boards are rejected due to solder mask printing or punching errors. The satisfactory boards are then deslugged by manual insertion of boards over a bed of carefully positioned pins to remove any blockage. Next, the boards are hand-fed into an

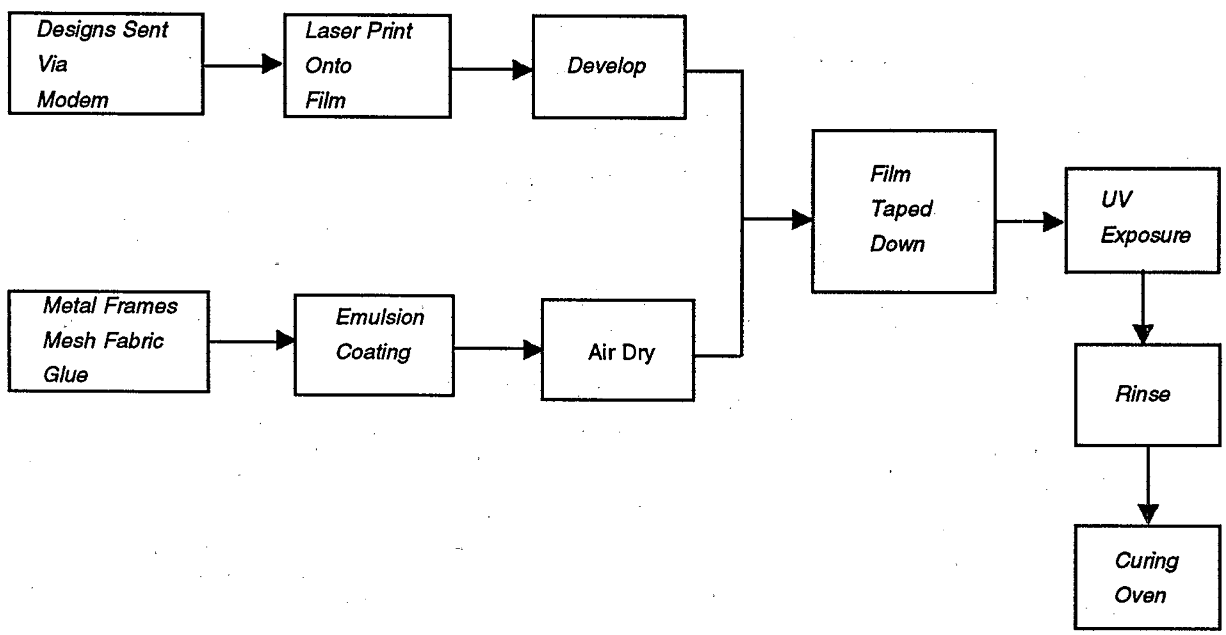

Figure 1. *Screen Production.*

automatic electrical tester, which rejects approximately 1% of incoming boards. All rejected boards are landfilled and constitute about 5% of incoming panel area. Finally, the boards are boxed, bar coded, and shipped. The circuit board production process is illustrated in Figure 2.

Etching

Etching removes the unnecessary copper coating, leaving the circuit pattern on the panels. Raw materials for the etching operation include hydrochloric acid, chlorine gas, caustic soda, and "Sur-Clean" micro-etch solution.

Panels from screen-printing inspection are conveyed through etch tanks. The etch solution is composed of hydrochloric acid, dissolved gaseous chlorine, and recirculated water from the rinse as needed. The solution is heated by the exothermic reaction of removing the copper and is maintained at 130°F by cooling water circulating in jackets around the tanks. Balance of the system is maintained automatically. Etch chamber solutions are bled to a storage tank as they become saturated with copper and are shipped weekly to a recycler. Fumes drawn off the etch tanks are diverted to a fume scrubber that operates 24 hr/day, 7 days/wk. The scrubber recirculates 20 gal/min of water with 1.5 gal/min of fresh water and a 1.5 gal/min overflow. Wastewater is discharged to the municipal sewer. Caustic soda is also added to the scrubber water.

The primary etch process is followed by a four-stage cascade rinse. Wastewater from this rinsing operation is dumped every 2 hr to the water treatment system. Following rinsing is a stripping etch resist bath that removes the etch mask from the panels. The solution is composed of caustic soda beads dissolved in water that is heated to 110°F. Water from this tank is continuously filtered to remove the stripped etch resist ink particles. Contaminated paper filters and etch resist sludge are landfilled. The stripping etch resist solution is dumped twice a week to the water treatment system. Fumes drawn off of the stripping etch resist tank are directed to the fume scrubber described earlier.

Next, the panels are sent through a two-stage countercurrent rinse. Wastewater from the rinse continually flows to the water treatment system. Finally, the panels are micro-etched to remove any oxides present. The micro-etch solution consists of Sur-Clean 92 solution and water. Spent solution is dumped twice a week to the water treatment system. Fumes collected over the micro-etch tanks are directed to the fume scrubber discussed earlier. Following micro-etch processing, panels undergo a two-stage countercurrent rinse after which they pass through a hot-air electric dryer at 130°F. Wastewater from the rinse continually flows to the onsite water treatment system. From the dryer, panels are stacked and transferred to the solder mask screen printing area.

Solder Coating

As mentioned earlier, the solder coating process is applied to approximately 10% of the product. This 10% is generally composed of boards that do not have surface-mounted components. The solder protects the copper that has leads attached. This process is outdated and has been replaced by the SealBrite process; however, the line is currently being used to reduce the load on the SealBrite line. Raw materials

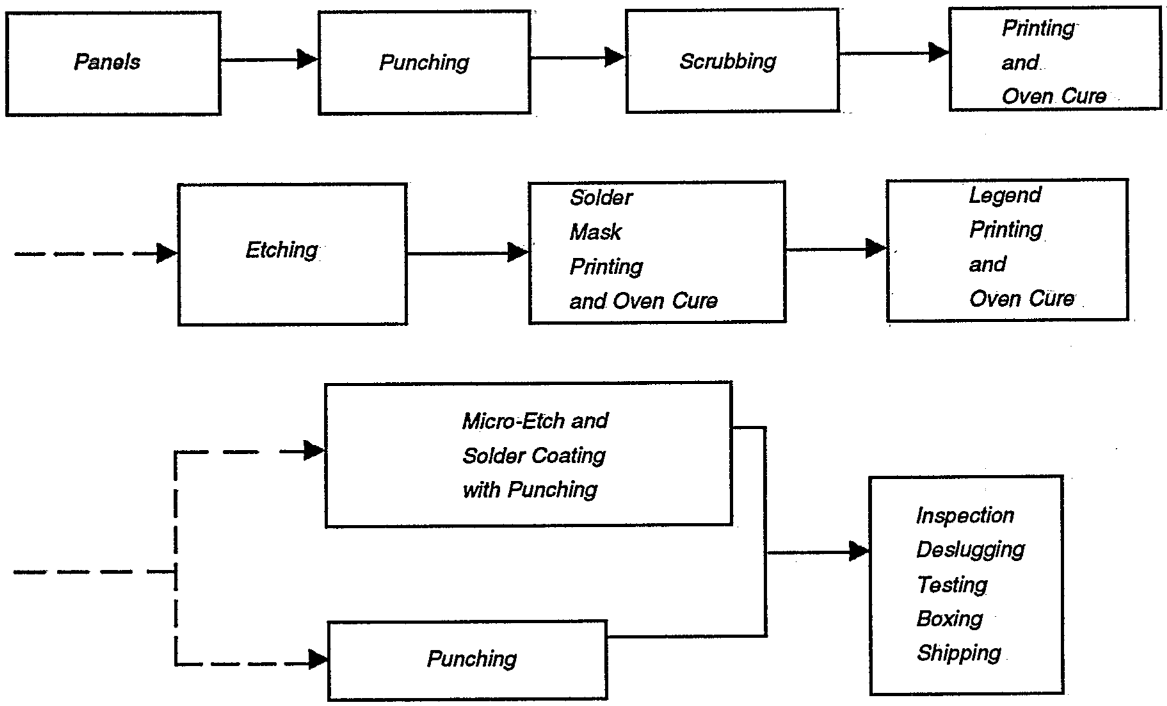

Figure 2. Circuit Board Production.

for this process include an acidic etch solution called Sur-Clean 92 solution, Organo Flux, roll salts, and solder.

Panels from the legend-printing process undergo a micro-etch solution spray consisting of Sur-Clean 92 solution and water. The micro-etch solution removes any oxides present and prepares the surface for soldering. Waste solution is dumped to the water treatment system. Panels are rinsed in a two-stage countercurrent spray system; water is continuously discharged to the water treatment system. Next, the panels are conveyed through a hot-air electric dryer at 100°F and through a flux tank in which Organo Flux is roll-coated onto the panels to promote solder adhesion. No waste is generated from the flux operation. Panels are preheated in an electric oven at 360°F and are roll-coated with tin/lead solder at 510°F. Roll salts are used to remove impurities from the solder bath. Waste "dross" (contaminated solder) is minimal and is disposed of in the municipal trash. After solder coating, the panels undergo a three-stage spray rinse. Fresh water enters the third tank and is recirculated into the first tank. The second tank water level is maintained by drag-out from the first tank. Wastewater is discharged to the water treatment system. Finally, the panels are conveyed through a hot-air electric dryer at 130°F and on to the punching operations described earlier in the description of Circuit Board Production.

SealBrite Coating

SealBrite coating is applied to 90% of the product. SealBrite compound functions similarly to solder, as a base for component attachment. Raw materials for this process include sulfuric acid, hydrogen peroxide, SealBrite, and SealBrite thinner. Isopropyl alcohol is used for cleaning the SealBrite tank.

Boards from the punching operations described under Circuit Board Production are micro-etched in a tank with a heated solution (100°F) consisting of sulfuric acid, hydrogen peroxide, and water. The etch removes any oxides that are present and prepares the surface for the SealBrite coating. The micro-etch tank is cleaned twice a year; bottoms are drained to the water treatment system. Cooling water circulates through a jacket around the tank and is added to a high-pressure spray rinse that follows the micro-etch. That rinse is followed by a four-stage cascade rinse; this water is added to the high-pressure spray rinse along with fresh water. Wastewater from the high-pressure spray rinse is sent to the water treatment system. The boards are conveyed through a hot-air vacuum dryer at 130°F and then through the SealBrite tank. SealBrite is roll-coated onto the boards. Thinner is added manually to the tank as needed. Isopropyl alcohol is used to clean the SealBrite roller periodically. Spent SealBrite solution is collected and shipped offsite as a hazardous waste. The coating is cured in an infrared oven at 250°F and then air cooled. Evaporated thinner from the oven is ducted to the outside atmosphere. After SealBrite processing, boards are then transported for inspection as previously described.

Wastewater Treatment System

Wastewater from various production processes is collected in a 500-gal holding tank. The initial pH of the mixed wastewater in the holding tank is in the approximate range of 7 to 8. From the holding tank, water is pumped into a 2,000-gal central tank for pH adjustment to 9 to 10 by addition of caustic liquid (sodium hydroxide). After pH adjustment, water is pumped at a rate of 45 gal/min through two electrochemical cells in series. These cells contain iron plates that convert copper salts to iron salts. The plates are periodically washed down with hydrochloric acid to prevent copper buildup and are changed every month. Hydrogen gas and hydrochloric acid exiting the tank are recirculated into the central tank, along with any copper ions washed from the plates. Water then flows through two degassing tanks in series that allow trapped hydrogen gas to be vented to the outside atmosphere. Wastewater is then pumped to a clarifier where floc and dispersant are added to promote sludge precipitation. Sludge is pumped to a sludge thickening tank for further settling and on to one of two filter presses. Decanted water from both operations is returned to the clarifier. Sludge is removed to the local landfill. The water from the clarifier is pumped to a mixing tank where plant cooling water, water from the fume scrubber, and water from the SealBrite line, which is collected separately in a holding tank, are mixed with the treated water and discharged to the municipal sewer.

Existing Waste Management Practices

- A computer-controlled regeneration system has been installed to maintain cupric chloride etch solution.

- Excess ink collected on screens in the screen-printing operations is manually scraped off and returned to the ink reservoir.

- Filter presses are used to reduce the volume of wastewater sludge shipped offsite.

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 time are also given in Table 2. 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 minimization opportunity, in most cases, 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.

Additional Recommendations

In addition to the opportunities recommended and analyzed by the WMAC team, four additional measures were considered. These measures were not completely analyzed because of insufficient data or minimal savings as indicated below. They were brought to the plant's attention for future reference, however, since these approaches to waste reduction may increase in attractiveness with changing plant conditions.

- Install an enclosed solvent cleaning system for the cleaning of screens to minimize the evaporation of solvent. Minimal savings and high capital costs are projected for this recommendation.

- Use reusable filters to remove ink from the stripping etch-resist caustic solution in place of paper filters. Minimal savings are projected for this recommendation.

- Replace the cupric chloride etch solution with a sulfuric acid/hydrogen peroxide etch solution. The proposed etch solution would generate considerably less waste and that waste would be more easily recoverable. A lengthy payback for this recommendation is predicted.

- Investigate the possibility of recovering the cupric chloride etch solution onsite.

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 ($)
Filters containing copper and zinc	Mechanical wet scrubbing operation in the circuit board production line.	2,700 lb	1,730*
Rags containing ink and xylene blend	Cleaning of screens and machines in the four screen-printing operations in the circuit board production line.	48,000 rags	21,890
Polyester screen mesh containing emulsion coating	Screen-printing operations in the circuit board production line.	23,880ft ^{2}	1,730*
Rejected circuit boards	Inspection process in the circuit board production line.	247,500ft ^{2}	2,080*
Panel webbing and slugs	Punching process in the circuit board production line.	643,500 ft ^{2}	35,600*
Spent etchant	Etch chambers associated with the etching process.	192,000 gal	110,530
Etch resist sludge	Filtering of solution from the stripping etch resist bath.	120 gal	1,730*
Contaminated paper filters containing etch resist	Filtering of solution from the stripping etch resist bath.	17,860 ft ^{2}	1,900*
Spent SealBrite solution	SealBrite coating process.	165 gal	7,330
Evaporated SealBrite thinner	SealBrite coating process.	275 gal	0**
Process wastewater	Various production processes, fume scrubber, and equipment cooling.	23,000,000 gal	56,750
Wastewater sludge	Onsite wastewater treatment system.	38,000 lb	14,160*

*Does not include the total cost of $720/yr for municipal landfill disposal. This charge is assessed regardless of the quantity of waste.
**Plant personnel report no costs associated with the management of this waste. There is a replacement cost associated with the evaporation.

Table 2. *Summary of Recommended Waste Minimization Opportunities*

Waste Stream Reduced	Minimization Opportunity	Annual Waste Reduction Quantity	Annual Waste Reduction Percent	Net Annual Savings, $	Implementation Cost, $	Payback Years
Wastewater	Install a closed-looped chilled water system, including an electric chiller, an outdoor condenser, and a storage tank, in order to use recirculated water for cooling the UV curing ovens and the etch tanks.	14,000,000 gal	60	40,000	76,640	1.9
Spent etchant	Install a steam generation system to heat the spent etch solution as it is transported from the etch tank to the storage tanks to drive off a portion of the water and thereby reduce the volume of waste shipped offsite. The steam produced should be directed to the plant's fume scrubber.	67,200 gal	35	33,510	28,180	0.8
Filters containing copper and zinc	Use reusable polymer membrane filters instead of paper filters for filtering copper and zinc from the wastewater of the mechanical wet scrubbing operation. Particles collected on the new filters should be scraped off and sold for recycle.	2,590 lb	96	3,100	7,700	2.5

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