REPORT

FINAL REPORT

CARBON BLACK DISPERSION PRE-PLATING TECHNOLOGY FOR PRINTED WIRE BOARD MANUFACTURING

CC

To

RISK REDUCTION ENGINEERING LABORATORY

U.S. ENVIRONMENTAL PROTECTION AGENCY

CINCINNATI, OHIO

SEPTEMBER 1993

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September 1993

CARBON BLACK DISPERSION PRE-PLATING TECHNOLOGY FOR PRINTED WIRE BOARD MANUFACTURING

Final Technology Evaluation Report

by

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Contract No. 68-C0-0003
Work Assignment No. 2-36

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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 (EPA) 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, Superfund-related activities, and pollution prevention. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Passage of the Pollution Prevention Act of 1990 marked a significant change in U.S. policies concerning the generation of hazardous and nonhazardous wastes. This bill implements the national objective of pollution prevention by establishing a source reduction program at the EPA and by assisting states in providing information about and technical assistance for regarding source reduction. In support of the emphasis on pollution prevention, the "Waste Reduction Innovative Technology Evaluation (WRITE) Program" has been designed to identify, evaluate, and/or demonstrate new techniques and technologies that lead to waste reduction. The WRITE Program emphasizes source reduction and on-site recycling. These methods reduce or eliminate transportation, handling, treatment, and disposal of hazardous materials in the environment. The technology evaluation project discussed in this report describes the use of a carbon black dispersion pre-plating technology as an alternative to electroless copper for through-hole plating during printed wire board manufacture. The carbon black pre-plating technology reduces wastes by reducing process steps and by avoiding the use of metals and hazardous materials.

E. Timothy Oppelt, Director
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ABSTRACT

This evaluation addresses the product quality, waste reduction, and economic issues involved in replacing electroless copper with a carbon black dispersion technology. McCurdy Circuits of Orange County, California, currently has both processes in operation. McCurdy has found that the product quality achieved with each process is equal. Sampling and analysis of the wastestreams and estimation of bath usage through this project has determined that the carbon black dispersion produces fewer quantities of waste. With this technology, rinse water usage is reduced from 13.8 gal per ft^2 to 1.72 gal per ft^2 of printed wire board surface. The total solids contained in the rinse water is reduced from 23,800 mg/ft^2 to 4,500 mg/ft^2 of board surface. Carbon black dispersion also eliminates some specific hazards resulting from the electroless copper technology, i.e., the use of formaldehyde and complexed copper. An economic analysis determined that the new process is cost efficient due to reduced chemical usage and a more efficient process. The payback period is less than 4 years for purchase of the system tested in this study. The new carbon black dispersion process was found to be a viable alternative to electroless copper.

This report was submitted in partial fulfillment of Contract Number 68-C0-0003, Work Assignment 2-36, under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 1991 to September 30, 1992, and work was completed as of September 30, 1992.

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The U.S. Environmental Protection Agency and Battelle wish to acknowledge the host site for this evaluation study, McCurdy Circuits, Orange, California. McCurdy Circuits personnel Keith Criscuolo, Charles McLaughlin, and Fred Scheer supplied relevant process information, helped conduct the testing, and reviewed the results of the testing. Their contributions allowed the evaluation study to proceed smoothly.

SECTION 1
INTRODUCTION

GENERAL OVERVIEW

The objective of the U.S. Environmental Protection Agency's (EPA's) Waste Reduction Innovative Technology Evaluation (WRITE) Program is to evaluate prototype technologies in the workplace that have potential for reducing wastes at the source or for preventing pollution. In general, each technology is evaluated on three issues.

First, the impact of the new technology on waste generation is measured. The new technology will be compared to the existing technology (baseline) or the process that it replaces. The waste generated from each technology is determined and the values are compared.

Second, the economics of the new technology must be quantified and compared with the economics of the existing technology. It should be mentioned that improved economics is not the only criterion for using a new technology. Justifications other than reduced costs would encourage implementing new approaches or technologies. Nevertheless, a measure of the economic impact of any potential change is useful.

Third, the effectiveness of the new technology is assessed. Waste reduction or pollution prevention technologies typically recycle or reuse materials, or use alternative materials or techniques. Therefore, it is important to verify whether the quality of the feed materials and the quality of the product are acceptable for the intended purpose.

This study evaluated a process that replaces electroless copper for through-hole plating in the manufacture of printed wire boards (PWBs). The new process uses a carbon black dispersion process to replace the electroless copper process. The following sections provide detail on the evaluation of this new process.

DESCRIPTION OF THE SITE AND TECHNOLOGY STUDIED

McCurdy Circuits of Orange County, California, the host test site for this project, produces PWBs at this site. One PWB manufacturing process line at McCurdy Circuits operates using electroless copper for the through-hole plating of PWBs. This study focused on a potential replacement process for electroless copper through-hole plating in PWB manufacturing operations.

The electroless copper process at McCurdy Circuits consists of 18 operational steps:

1. Acid cleaner
2. Rinse (to discharge line)
3. Microetch (sodium persulfate solution)
4. Rinse (to ion exchange line)
5. Activator–pre-dip
6. Catalyst
7. Rinse (to discharge line)
8. Rinse (to discharge line)
9. Accelerator
10. Rinse (to discharge line)
11. Electroless copper
12. Rinse (to separate ion exchange system)
13. Sulfuric acid 10%
14. Rinse (to ion exchange system)
15. Anti-ox
16. Rinse (to discharge line)
17. Deionized (D.I.) water rinse (to discharge line)
18. Forced air dry

In the first 17 steps, racks of PWBs are moved from tank to tank with an automated hoist. The sequence is shown in Figure 1. All the rinses are single flow through, which generates more wastewater than cascading or multiple-use rinses. The rinses following the electroless copper bath (Step 11) receive complexed copper from the bath due to drag out. This complexed copper, which is discharged with the rinse water, is hard to treat by typical metal hydroxide precipitation. The electroless copper process line rinse water is collected in one of three drain lines, as shown in Figure 1. One drain line goes to a discharge line (Sampling Point #1), one goes to the first ion exchange collection system (beyond Sampling Point #2), and one goes to an ion exchange system for the electroless copper rinse (Sampling Point #3).

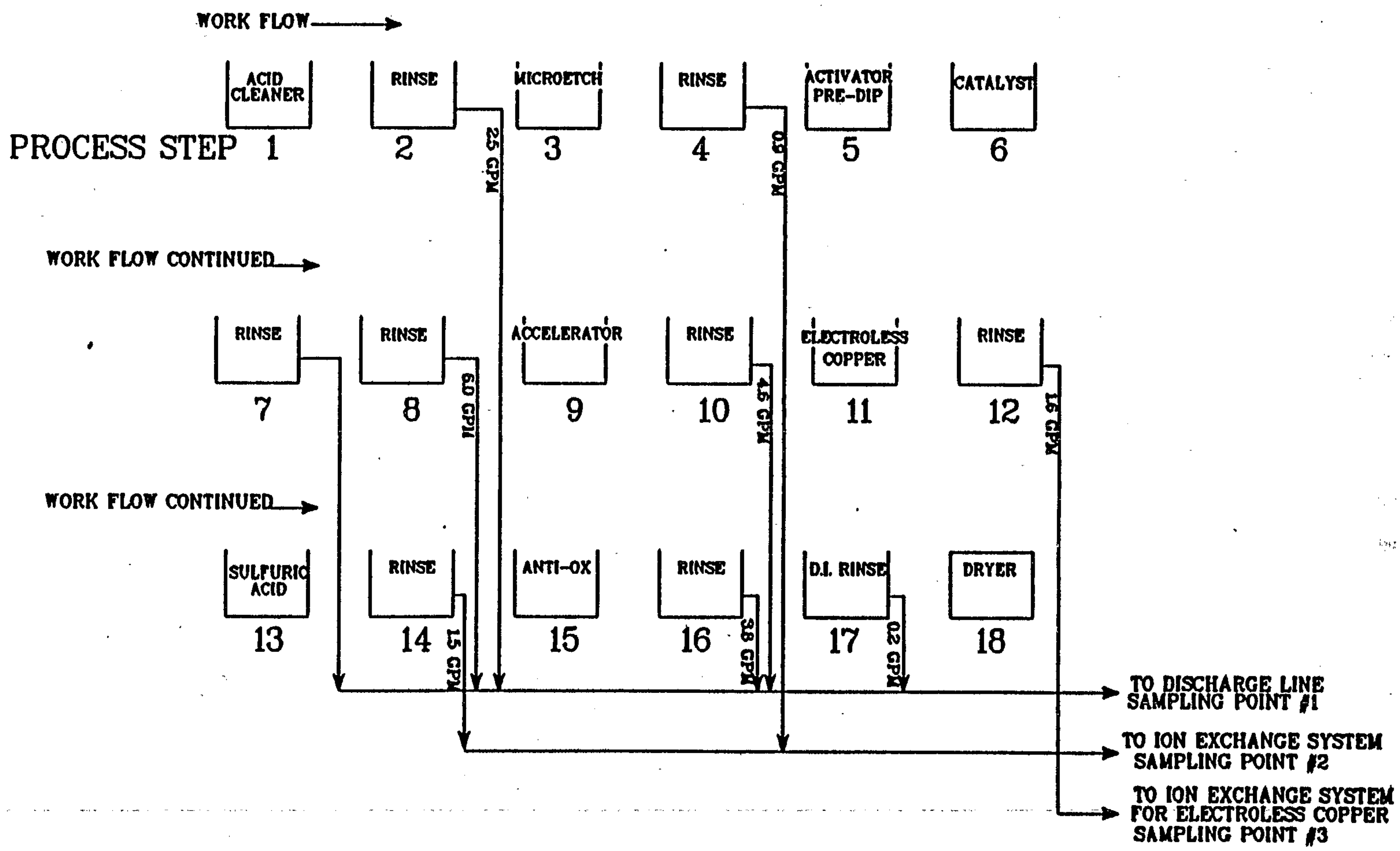

Figure 1. Electroless Copper Process Line Used for Pre-Plating

The carbon black dispersion pre-plating process being evaluated in this study replaces the electroless copper process used for through-hole plating. Whereas the electroless copper process is essentially a batch process, the carbon black process is a continuous system in which parts are placed on a conveyor belt and run through as often as needed. This carbon black dispersion technology, termed BLACKHOLE™ Technology by the vendor who invented it, consists of fewer baths and a more simplified process with only 11 process steps:

1. BLACKHOLE™ cleaner
2. Rinse (water from step 4, to discharge line)
3. BLACKHOLE™ conditioner
4. Rinse (fresh tap water, to rinse #2)
5. BLACKHOLE™ bath
6. Dryer
7. Microetch
8. Rinse (water from step 10, to ion exchange system)
9. Anti-tarnish
10. Rinse (fresh tap water)
11. Dry

Figure 2 shows the progression of steps 1 through 10. The BLACKHOLE™ bath (Step 5) is an aqueous carbon black dispersion, which eliminates the need for electroless copper metallization prior to electrolytic plating. The steps prior to and following Step 5 are similar to those used in the electroless copper process. The vendor literature provided in Appendix A more fully describes the process steps.

When using the BLACKHOLE™ Technology, Steps 1 through 6 are performed sequentially. Then these steps are repeated without the cleaner step (Step 1) to provide extended exposure to the carbon black suspension solution in the BLACKHOLE™ bath (Step 5), followed by Steps 7 through 12, performed sequentially. These steps are done automatically in a horizontal conveyor system at McCurdy Circuits, as shown in Figure 2. Repetition of the first part of the sequence was deemed necessary to increase the treatment time in the BLACKHOLE™ process bath because the equipment at McCurdy Circuits is an early version. Current equipment is designed to provide a longer treatment time, thus eliminating the need to repeat steps 1 through 6. Unlike the electroless copper process, with BLACKHOLE™ Technology the rinse after the microetch process step is the only rinse water stream that goes to the commingled ion exchange system (beyond Sampling Point 5) that is shared with the first ion exchange system for the electroless copper process. The rest goes to the discharge line.

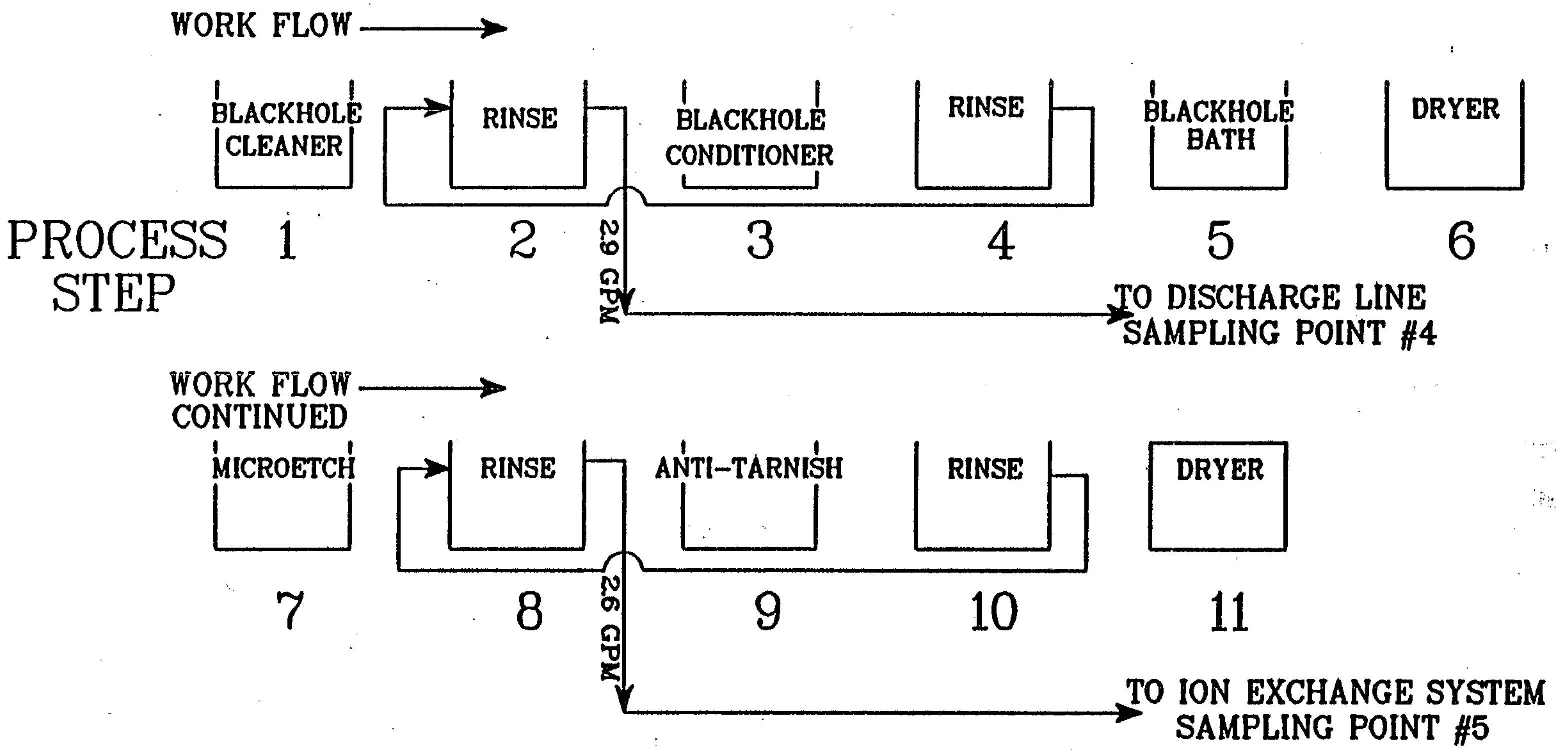

Figure 2. BLACKHOLE™ Technology Line Used for Carbon Black Dispersion Pre-Plating

Wastewater is treated at McCurdy Circuits by means of two ion exchange systems that collect copper from the rinse water. The first (commingled) ion exchange system is for copper-containing rinse waters from both processes, whereas the other ion exchange system is for the complexed copper from the rinse following the electroless copper bath. The regenerant solution from the commingled ion exchange system is passed through an electrowinning system to plate out copper for sale as scrap. After that, it is treated again to precipitate out residual metals. Upon filtration, these precipitated metals form a cake that is placed in drums and shipped out for disposal.

The carbon black dispersion process has fewer processing steps than the electroless copper process. Carbon black dispersion uses only two rinse water flows, and the process solutions contain nonhazardous materials. During the McCurdy Circuits evaluation, the carbon black dispersion process was operated side-by-side with the electroless copper process for comparison.

LITERATURE SURVEY

The carbon black dispersion process has been available commercially since 1989. Military Standard MIL-P-55110D permits through-hole plating technologies other than electroless copper, and the BLACKHOLE™ Technology process is one alternative accepted under this Military Standard. This military standard for PWBs establishes the qualification and performance requirements for rigid single-sided PWBs, rigid double-side PWBs, and rigid multi-layer PWBs with plated through-holes.

The literature search done in conjunction with this study turned up three published papers (Bracht and Piano, 1990; Murray, Sept. 1989; Murray, Dec. 1989) and three technical papers. The first technical paper (Marien and Pendleton, nd), presented at the 5th Printed Circuit World Convention, dealt with "Plating-Through-Hole Colloid and Surface Phenomena." The paper describes some surface and colloid phenomena occurring during through-hole surface preparation. It examines the choice of epoxy resin smear removal chemistry and the change in density needed to achieve optimum coating of the carbon black dispersion in the through-hole.

The second technical paper (Polakovic, 1988) describes and evaluates the BLACKHOLE™ process. The evaluation includes test results. The third technical paper (Greenberg, 1988) updates Polakovic's paper. Greenberg compares BLACKHOLE™ Technology to the electroless copper process and details the technology's progress with regard to practical aspects of surface treatment.

The Bracht and Piano article in *Printed Circuit Fabrication* considers the environmental advantages of the BLACKHOLE™ Technology.

One of Murray's articles in *Circuits Manufacturing* (1989b) discusses various methods for plating small holes (which are typically difficult to plate). In the discussion of the BLACKHOLE™ process, Murray concludes that BLACKHOLE™ is successful because it lays a better base for electrolytic plating than does electroless copper. Murray also states that, with the addition of the new process, Marlo Circuits has obtained a 30% reduction in wastewater treatment costs and a faster delivery of higher quality parts. The other article by Murray (1989a) focused on applications of the BLACKHOLE™ process at several manufacturers. Murray talked to engineers at Circuit Technology who decided to install a BLACKHOLE™ production line after being impressed by a trial period that resulted in a drop in waste treatment, excellent yields, and an increase in throughput. Several other satisfied customers were cited, including McCurdy Circuits.

Two indirectly related articles (Metzger et al., 1990; Nakahara, 1992) describe an alternative process to electroless copper — the "direct metallization system" (DMS). This process uses conductive organic polymers to provide a good basis for copper adhesion.

STATEMENT OF PROJECT OBJECTIVES

The goal of this study was to compare the wastes generated from the carbon black dispersion process using BLACKHOLE™ Technology with those generated in using the electroless copper process in PWB production. This study had two major objectives:

- Evaluate the waste reduction potential of the carbon black dispersion technology.
- Evaluate the cost effectiveness of the carbon black dispersion technology compared to that of the electroless copper process.

The focus of the study was waste reduction and economics. Product quality was a secondary issue. The study used McCurdy Circuits and their customers' acceptance of the PWBs as evidence of the product quality and acceptance.

SECTION 2
CONCLUSIONS AND RECOMMENDATIONS

The main focus of this study was the waste reduction potential of the carbon black dispersion process using the BLACKHOLE™ Technology. The carbon black dispersion process achieved waste reduction through the reduced number of process steps and the reduced hazard of the chemicals used in the process. Table 1 summarizes the waste reduction achieved during this process evaluation. Rinse water use was reduced by a factor of eight, from 13.8 gal/ft^2 of PWB to 1.72 gal/ft^2. Chemical usage dropped considerably for the carbon black dispersion process. Although the exact chemicals and compositions are different for each process such that direct comparisons cannot be made, some of the bath compositions are similar. For example, the cleaner used in each process (monoethanolamine) is reduced from 150.5 gal/yr using the electroless copper process to 21.4 gal/yr using the carbon black dispersion process.

Copper waste in the rinse water is reduced 23% using carbon black dispersion. This does not take into account the copper lost due to replacement of the electroless copper solution. Each day, 20% of the 100-gallon electroless copper bath is replaced. A copper solution concentration of 2 grams per liter removed from the bath results in a loss of 83.4 pounds per year of copper based on a 50-week

TABLE 1. SUMMARY OF WASTE REDUCTION

Waste Types	Electroless Copper Process	BLACKHOLE™ Process	Net Change in Waste
Rinse Water	13.8 gal/ft^2	1.7 gal/ft^2	12.2 gal/ft^2
Chemical Usage (Section 4)	11,755 gal + 38 lbs	90 gal + 611 lbs	not calculable
Copper Waste (in rinse water)	324 mg/ft^2	248 mg/ft^2	76 mg/ft^2
Total Solids	23,800 mg/ft^2	4,510 mg/ft^2	19,300 mg/ft^2

year. The copper found in the carbon black dispersion rinse water is removed from the PWBs themselves during microetching. No additional copper is introduced in the carbon black dispersion baths during processing.

The quantity of total solids leaving with the rinse water is reduced by a factor of five using the carbon black dispersion process. The reduction in solids results from the reduced use of rinse water and the fewer number of process baths used by the carbon black dispersion process. The reduced solids indicate that fewer bath chemicals are lost and that fewer chemicals are discharged to the wastewater treatment system.

The carbon black dispersion process uses five chemical process baths and four rinse baths. The chemical process baths avoid the introduction of hazardous metals and materials. Chemical baths in the electroless copper process contain the metals palladium and copper, and formaldehyde (Section 4). The carbon black dispersion process eliminates the use of both palladium, which is the catalyst used in the electroless copper process, and formaldehyde, a significant health hazard.

Table 1 does not include the waste generated during ion exchange. McCurdy Circuits periodically replaces ion exchange columns. These have a small impact on the overall system.

In addition to the long-term environmental aspects of waste reduction using carbon black dispersion, the hazard reduction of this process has immediate advantages. Eliminating the use of formaldehyde diminishes the health risks to the personnel involved in handling the baths, as well as the industry's potential environmental liabilities. Fewer regulations may be imposed on the PWB industry because of the reduced hazard. The reduced number of process steps and quantities of chemicals used also reduces storage and transportation requirements, thus minimizing the possibility of leaks and accidental spills during storage and transportation. These same factors also result in economic savings that are too varied and intangible to be included in the analysis of economic factors during this study.

The economic analysis of this study showed the carbon black dispersion process using BLACKHOLE™ Technology to be cost effective. Section 4 compares the operating costs of the two evaluated processes. Carbon black dispersion has an annual operating cost of approximately half that of the electroless copper process. A continuous horizontal carbon black dispersion process line that can process 50 to 100 PWBs per hour costs approximately $200,000 to purchase. Combining this with operating savings detailed in Section 4 provides a payback period of less than 4 years if the cost of capital is assumed to be 15%. The option of converting electroless copper equipment to the carbon black dispersion process would reduce the capital cost and result in an even faster payback period.

The energy costs of using both process lines were assumed to be almost equal. There was no readily available method to determine the energy usage of each line. Both lines have heated baths, equipment conveyors, and driers. The difference in energy usage between the two lines should not significantly affect the economics.

The actual waste treatment costs at the test site were unavailable. In both processes performed at McCurdy Circuits, copper-containing wastewater is passed through an ion exchange resin to remove the copper before entering the discharge line. The copper is eluted from the resin and recovered by electrowinning. The copper is then given away as scrap. A plant that operates a conventional wastewater treatment system consisting of pH adjustment and precipitation would realize a significant savings in treatment costs with the carbon black process because of the reduction in copper waste. This option was not included in our evaluation.

Product quality, as determined by an inventory of rejects during the study at McCurdy Circuits, was similar to that of the electroless copper process. The carbon black dispersion process achieved an acceptable product. PWBs processed by carbon black dispersion using the BLACKHOLE™ Technology have also passed MIL-STD-55110D qualification and performance standards for plated through-holes.

In conclusion, the carbon black dispersion process reduces wastes, avoids many hazardous chemicals and metals, is cost effective, and yields an acceptable product. Therefore, this process should be considered a viable alternative to the electroless copper process. If the shop involved is a job shop, client input and requirements would be important in determining the feasibility of incorporating the carbon black dispersion process. This report presents the waste reduction potential and economic savings of carbon black dispersion using the BLACKHOLE™ Technology for McCurdy Circuits. Although this report can provide generalizations for other companies, it is recommended that each company examine the specific requirements and the suitability of using carbon black dispersion for its particular needs.

SECTION 3
METHODOLOGY

WASTE REDUCTION POTENTIAL

The amount of waste resulting from the electroless copper operation, run at full production, was evaluated to represent baseline data. The amount of waste from the carbon black dispersion process using BLACKHOLE™ Technology, run at full capacity, was then compared to this baseline. The wastestreams from both processes consisted of the bath solutions (discarded periodically) and the rinse water. The volumes of these wastestreams were obtained from plant records (bath volumes) and field measurements (rinse water flow). Bath composition is known and maintained by McCurdy Circuits. The pollutant content of the bath solutions was estimated from plant records of the chemical makeup of the baths. The pollutant content of the rinse water was obtained by analysis of samples collected during field testing. Measurable factors in analyses to characterize the rinse water included copper, pH, and total solids content.

Samples from both processes were obtained to analyze the pollutants in the rinse water. Six sample sets for the electroless copper line and 11 sample sets for the carbon black dispersion process line were taken over 3 to 4 days of operations. Composite samples were required to allow for the cyclic concentration swings of the rinse water due to batch rinsing operations of the racks used in the electroless copper line. The composite samples were taken by a small metering pump that pulled a continuous sample of the rinse water as it left the process line. The sampling point was in the drain line after the rinse water had been well mixed but before other water sources had been added. The electroless copper process has three drain lines, and the carbon black process has two drain lines. Because electroless copper is basically a batch process, a composite sample was taken that would cover five cycles, or 90 minutes. On the other hand, the carbon black process is continuous and reaches steady state rather quickly. It has little variability because it is not done in batches. Therefore the sampling time was 10 minutes. Table 2 lists the samples from each drain line.

The sampling system for obtaining composite samples was flushed with clean water between samples to avoid contamination. The sampler also was operated for 5 minutes before any sample was collected to flush out both water from the sampling system and materials introduced during placement of the sampling line into the process drain line.

TABLE 2. SAMPLE SUMMARY

Sample Location	Sample Number	Sampling Time
Electroless Copper (EC)		
Discharge Line	EC-1S, EC-2S, EC-3S, EC-4S, EC-5S, EC-6S	90 Min
Complexed Ion Exchange Line	EC-1C, EC-2C, EC-3C EC-4C, EC-5C, EC-6C	90 Min
Ion Exchange Line	EC-1I, EC-2I, EC-3I, EC-4I, EC-5I, EC-6I	90 Min
BLACKHOLE™ (BH)		
Discharge Line	BH-1S, BH-2S, BH-3S ...BH-11S	10 Min
Ion Exchange Line	BH-4I, BH-5I, BH-9I, BH-10I, BH-11I	10 Min

All containers were prewashed before use, per Standard Method 1070. The bottles were labeled and placed in a cooler in the field for transportation to the laboratory. The bottles, if glass, were wrapped in bubble wrap to prevent breakage. The samples were packed in ice. The sample cooler was then labeled and shipped out via Federal Express to the laboratory with a chain-of-custody form.

The analytical methods used for this study are all published standard methods. The copper content in rinse water was measured using inductively coupled plasma spectrometry or equivalent by EPA Method 200.7. Total solids were measured by EPA Method 160.2. Only pH measurements were taken in the field (by EPA Method 150.1), so the pH meter was the only analytical instrument that needed to be calibrated in the field. Calibration solutions were taken for daily field calibration. A backup meter also was taken to the test site.

The rinse water flow rates of the two processes were determined, using the rinse tank as a receiving vessel. A stopwatch was used to measure the time required to raise the water level by 2 inches after the rinse tank outlet had been plugged. The rinse water flows were controlled either by restricting the flow orifices that maintained a constant flow of water to each rinse tank over time, or by a manually set ball valve. The flow remained constant so long as the city water pressure was consistent.

The city water pressure was not expected to vary significantly over the sampling time period, but if it did, it affected both lines equally. The flow to each rinse tank in the process was totaled for the total rinse water flow for the process. This flow and the material concentrations were used to determine the quantity of waste discharged from each process in the rinse water.

ECONOMIC EVALUATION

The economic evaluation was based on data obtained from McCurdy Circuits, including chemical costs and amounts used, and the cost and amount of water used. The current capital cost of carbon black dispersion equipment was obtained from an equipment vendor. The economic data were processed through an economics program based on worksheets provided in the *Facility Pollution Prevention Guide* (EPA, 1992) and modified to fit the project. This program includes taxes, inflation, depreciation, and cost of capital. (Cost of capital is the amount of interest the firm could have made if the capital cost of equipment were otherwise invested.) The program output projected a year-by-year return on investment.

PRODUCT QUALITY

The performance of the carbon black dispersion process using BLACKHOLE™ Technology in meeting product quality and performance was based on results of previous tests done in accordance with the Military Standard MIL-P-55110D requirements for through-hole plating. No additional testing was conducted during this evaluation, because the tests involved destructive testing of a number of PWBs and were time-consuming. McCurdy Circuits routinely conducts their own internal quality checks of 10% of the PWBs. During these checks, small coupons are punched from selected PWBs, cast in resin, and polished to allow visual inspection of through-hole plating and layer bonding. Also, the PWBs are placed on a test grid that checks continuity of the circuits. These quality checks made by McCurdy Circuits and inspections by their clients provided verification of product quality.

SECTION 4
RESULTS AND DISCUSSION

WASTE REDUCTION

The waste reduction assessment found that the production rate on the carbon black dispersion process line using BLACKHOLE™ (BH) Technology, i.e., 3.3 ft^2/min, is 2.1 times as fast as the production rate on the electroless copper (EC) process line, i.e., 1.6 ft^2/min. Production rates were timed during the field testing and compared to production schedules maintained by McCurdy Circuits. The production rate of 8 hrs/day, 5 days/wk, for 50 wks/yr assumed for this study is the approximate rate at McCurdy Circuits. McCurdy Circuits operates the electroless copper process at approximately full capacity of 1.6 ft^2/min, which yields 200,000 ft^2/yr. The carbon black process line was installed in response to increased demand, but it is not yet accepted by all clients, and thus is not operated at full capacity. In fact, it is operated at about 11% of its capacity. Equivalent productions must be used to compare the waste types and quantities generated by both processes. In this study, it was assumed that the carbon black process could completely replace the electroless copper process. Therefore, the waste reduction numbers reflect the potential production of the carbon black process at McCurdy Circuits, not the actual production. The calculations described below are based on the wastes that would be generated if each process were operated at capacity for 1 year and then an adjusted total for the carbon black process. The total is adjusted to account for the fact that the carbon black process would have processed twice the number of PWBs as the electroless copper process. In this way, wastes generated can be compared for equivalent annual productions.

The waste reduction potential of the carbon black process is twofold. First, the volume of wastewater is reduced. Less water wasted means less water that must be treated both before and after use, saving both resources and treatment chemicals. Second, the pollutant volume is reduced. A lower pollutant load not only requires less treatment, it also reduces the potential risk to both employees and the environment.

Reduction in Wastewater Volume

To determine the reduction in wastewater volume, both the continuous rinse water volumes and the volumes of discarded bath solutions must be measured. The bath volumes in the electroless copper (EC) and BLACKHOLE™ (BH) processes were obtained from plant records and confirmed by dimensional measurements. Table 3 lists these bath volumes and shows how often each bath is completely changed. Table 4 presents the rinse water flow rates for the EC and BH processes, as measured during the field visit. The flow rates from rinse tanks 8 (6.0 gpm) and 10 (4.6 gpm) using the EC process were higher than usual at the time of testing. Because these rates are not often adjusted, they were assumed to be accurate. However, McCurdy Circuits prefers to run these rinses at approximately 2 gpm. If the lower rate were assumed, the volume reduction and economic impact would be slightly lower (i.e., 82% water volume reduction instead of 87%; with no noticeable change in return on investment).

Table 5 shows the annual water use for each process, assuming 8 hr/day of operation, 5 days/wk, for 50 wk/yr. Table 5 includes the water used for bath makeup, which occurs weekly for

TABLE 3. BATH VOLUMES

Description	Volume (gal)	Replacement Frequency
Electroless Copper		
Acid Cleaner	50	weekly
Microetch	50	weekly
Activator	50	weekly
Catalyst	50	(a)
Accelerator	50	weekly
EC	100	(b)
Sulfuric Acid	50	weekly
Anti-Ox	50	weekly
BLACKHOLE™		
Cleaner	25	biweekly
Conditioner	25	biweekly
BLACKHOLE™	50	(a)
Microetch	50	biweekly
Anti-Tarnish	25	biweekly

(a) The bath is not discarded, only replenished, as shown in Table 6.
(b) ~20% discarded daily (the equivalent of 100% replacement in 5 days).

TABLE 4. RINSE WATER FLOW RATES

	Rinse Tank Number	Flow Rate (gpm)	Destination
Electroless Copper			
	2[a]	2.5	To discharge line
	4	0.9	To ion exchange
	7	1.4	To discharge line
	8	6.0	To discharge line
	10	4.6	To discharge line
	12	1.6	To complexed ion exchange
	14	1.5	To ion exchange
	16	3.8	To discharge line
	Total	22.3	
BLACKHOLE™			
	2[b]	2.9	To discharge line
	8	2.6	To ion exchange
	Total	5.5	

(a) Numbers in this column refer to steps in Figure 1.
(b) Numbers in this column refer to steps in Figure 2.

most baths (see Table 3). As seen in this table, the BH process uses much less water compared to the EC process. These water volume figures indicate that a smaller quantity of wastewater treatment chemicals would be needed, because less wastewater would be generated.

Reduction in Pollutant Volume

To determine the reduction in pollutants in the wastestream, pollutant levels in the baths, the solution discard rate, and the mass flow of pollutants in the rinse water must be measured. Table 6 lists the chemical makeup of each bath in the EC and BH processes derived from plant and supplier records. Also shown is the bath life and the amount of each chemical added to the bath throughout the week.

The annual usage (50 weeks) of each chemical shown in Table 7 is based on the data from Table 6. The annual numbers are then adjusted for the different production rates on each line. As seen in Table 7, the overall chemical usage is much lower in the BH process than in the EC process.

TABLE 5. ANNUAL WATER USE VOLUME

Description	Annual Volume[(a)] (gallons)
Electroless Copper	
Acid Cleaner	2,500
Microetch	2,500
Activator	2,500
Catalyst	N/A
Accelerator	2,500
EC	N/A
Sulfuric Acid	2,500
Anti-Ox	2,500
Rinses	2,680,000
Total	2,695,000
BLACKHOLE™	
Cleaner	625
Conditioner	625
BLACKHOLE™	N/A
Microetch	1,250
Anti-Tarnish	625
Rinses	670,000
Total	673,000
Adjusted Total[(b)]	336,000

(a) Annual volumes obtained from bath volume (Table 3) multiplied by dumping frequency and total rinse water flow rates (from Table 4) × 60 min/hr × 8 hr/day × 5 day/wk × 50 wk/yr.

(b) Adjusted to the same annual production as the electroless copper process line.

However, an exact comparison cannot be established due to the different chemicals used in each process. Although a general idea of the hazard of each chemical is known from their respective Material Safety Data Sheets (MSDSs), the proprietary nature of the formulations makes a compound-by-compound assessment difficult.

One chemical compound, formaldehyde, is completely eliminated from use by switching to the BH process. As seen in Tables 6 and 7, formaldehyde is not present in any of the BH process formulations, but approximately 200 gallons per year are used in the electroless copper bath (Table 7).

TABLE 6. CHEMICAL USAGE

Description	Initial Makeup of Bath[(a)]	Total Addition Throughout Week (Avg.)[(b)]	Bath Life
Electroless Copper			
Acid Cleaner	2.5 gal	0.394 gal	1 Week
Microetch			1 Week
Sulfuric Acid	0.75 gal	3.88 gal	
Sodium Persulfate	37.5 lbs	0	
Activator	50 gal	0	1 Week
Catalyst			Indefinite[(c)]
Pre-dip	48.5 gal	0.317 gal	
Catalyst	1.5 gal	0.435 gal	
Accelerator	5.0 gal	2.86 gal	1 Week
EC			Indefinite[(c)]
Copper	300 g	78.9 gal	
Sodium Hydroxide	1,000 g	45.0 gal	
Formaldehyde	0.25 gal	3.97 gal	
Sulfuric Acid	5 gal	1.16 gal	1 Week
Anti-Ox	25 gal	0	1 Week
BLACKHOLE™			
Cleaner	0.634 gal	0.507 gal	2 Weeks
Conditioner	1.27 gal	0.193 gal	2 Weeks
BLACKHOLE™	50 gal	1.36 gal	Indefinite[(c)]
Microetch			2 Weeks
Sodium Persulfate	45 lbs	0	
Sulfuric Acid	0.528 gal	0	
Copper Sulfate	2 lbs	0	
Anti-Tarnish			2 Weeks
CTCS 501	0.264 gal	0	
Sulfuric Acid	0.132 gal	0	

(a) From McCurdy Circuits Operations Manual.

(b) Data obtained from bath additions made during test week at McCurdy Circuits. In the case of the BLACKHOLE™ process, the original data were modified to reflect amounts that would have been added if the process were operated at the same capacity as the electroless copper line.

(c) Baths are not discarded. For the catalyst, addition is to make up for drag out; for EC, it is make-up for daily purge of 20% of the bath solution.

TABLE 7. ANNUAL CHEMICAL USAGE[a]

Description	Annual Chemical Usage	Annual Usage (Adjusted)
Electroless Copper		
Acid Cleaner	145 gal	145 gal
Microetch		
Sulfuric Acid	195 gal	195 gal
Sodium Persulfate	1,880 lbs	1,880 lbs
Activator	2,500 gal	2,500 gal
Catalyst		
Pre-dip	15.9 gal	15.9 gal
Catalyst	21.8 gal	21.8 gal
Accelerator	393 gal	393 gal
EC		
Copper	3,950 gal	3,950 gal
Sodium Hydroxide	2,250 gal	2,250 gal
Formaldehyde	199 gal	199 gal
Sulfuric Acid	308 gal	308 gal
Anti-Ox	1,250 gal	1,250 gal
BLACKHOLE™		
Cleaner	41.2 gal	20.6 gal
Conditioner	41.4 gal	20.7 gal
BLACKHOLE™	68.0 gal	34.0 gal
Microetch		
Sodium Persulfate	1,130 lbs	585 lbs
Sulfuric Acid	13.2 gal	6.6 gal
Copper Sulfate	50.0 lbs	25.0 lbs
Anti-Tarnish		
CTCS 501	6.60 gal	3.30 gal
Sulfuric Acid	3.30 gal	1.65 gal

(a) Annual usage based on (50 wk/bath life in weeks) (initial makeup + weekly additions).

Formaldehyde is a suspected human carcinogen that poses a significant health hazard when inhaled or ingested or through direct physical contact. Among other health problems, it can cause difficulty in breathing, pulmonary tract injury, severe abdominal pain, and even death. Palladium and trace amounts of cyanide, also used in the electroless copper process, are not present in the carbon black dispersion process.

Tables 8 and 9 show the results of the rinse water sample analyses from the electroless copper process and BLACKHOLE™ process, respectively. These samples were collected during field testing. Before being compared, the data must be normalized to account for the different flow rates in each rinse and for the difference in production rates. To obtain numbers for comparison, the concentrations in milligrams per liter were first multiplied by the respective flow rates and converted to milligrams per minute, thus adjusting them for the varying flow rates. The milligrams per minute numbers were then added to obtain totals for each process. For BLACKHOLE™ (Table 9),

$$(2.53 \text{ mg/L} \times 2.9 \text{ gpm} \times 3.785 \text{ L/gal}) + (62.3 \text{ mg/L} \times 2.6 \text{ gpm} \times 3.785 \text{ L/gal}) = 641 \text{ mg/min})$$

These totals are then divided by the production rates (641 mg/min / 3.3 ft^2/min = 194 mg/ft^2) to obtain the milligrams of pollutant per feet square of PWB processed. These milligrams per feet squared numbers, shown in the right-hand columns of Tables 8 and 9, are now comparable quantities.

Averages and standard deviations, shown in Table 10, were calculated, and a Student's t-test was performed with a 95% level of confidence. The test statistic, which takes into account the standard deviations, indicates that the levels of both copper and total solids discharged by the BH process are significantly lower than those for the EC process. The average reduction in copper is 76 mg/ft^2, a reduction of 23%. The average reduction in total solids is 19,300 mg/ft^2, a reduction of 81%.

The BH process thus releases significantly less copper into the wastestream. If approximately 200,000 ft^2 of PWB (the operating capacity of the EC process) were run on both processes, the reduction in copper waste would average 15.2 kg (33.4 lb) per year.

The lower total solids discharge when using the BH process results from fewer chemical process baths and a faster production rate. Although the higher solids composition of the BH baths would lead one to expect that the BH process would discharge more solids, a faster production rate and fewer process baths containing chemicals apparently offset this effect when the data are normalized.

TABLE 8. ELECTROLESS COPPER ANALYTICAL RESULTS

Composite taken over 90 minutes	Discharge Line[a] (18.3 gpm)			Rinse Line to Ion Exchange[b] (2.4 gpm)			Rinse Line to Ion Exchange for Complexed Copper[c] (1.6 gpm)			Totals[d]	
Sample No.	Total Solids[e] mg/L	pH[f] S.U.	Copper[g] mg/L	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/ft^2	Copper mg/ft^2
EC-1	0	7.21	0.212	96	3.78	28.5	0.025	5.85	4.24	546	187
EC-2	128	7.02	0.375	296	2.66	57.4	0.025	6.65	3.18	7,220	354
EC-3	0	7.47	0.390	268	2.82	62.1	0.025	9.13	3.34	1,520	382
EC-4	740	7.53	0.464	1,240	3.40	47.6	508	9.75	4.46	41,000	307
EC-5	852	7.50	0.352	1,340	3.01	63.6	400	8.91	2.38	46,000	385
EC-6	892	7.19	0.385	1,160	2.97	53.5	296	6.19	2.13	46,300	328
Results	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/ft^2	Copper mg/ft^2
Average (mg/L)	435	7.32	0.363	733	3.11	52.1	201	7.75	3.29	23,800	324
Std. dev.	436	0.21	0.083	570	0.41	13.0	230	1.70	0.94	22,800	73.6

(a) Analysis of samples taken from electroless copper discharge line. See Table 4 for all rinse water flows to discharge line.
(b) Analysis of samples taken from line to ion exchange from electroless copper line. See Table 4 for all rinse water flows to ion exchange.
(c) Analysis of samples taken from line to complexed ion exchange electroless copper line. See Table 4 for all rinse water flows to complexed ion exchange.
(d) Total pollutant per ft^2 calculated from [(discharge line flow, 2.9 gpm) (3.785 L/gal) (pollutant conc. in discharge line, mg/L) + (ion exchange flow, 2.6 gpm) (3.785 L/gal) (pollutant conc. in line to ion exchange, mg/L)]/the processing rate, ft^2/min.
(e) Total solids were measured using EPA Method 160.2.
(f) pH was measured using EPA Method 150.1; S.U. = standard unit.
(g) Copper was measured using EPA Method 200.7.

TABLE 9. BLACKHOLE™ ANALYTICAL RESULTS

Composite taken over 10-minute period	Discharge Line (2.9 gpm)			Ion Exchange (2.6 gpm)			Totals[a]	
Sample No.	Total Solids mg/L[b]	pH S.U.[c]	Copper mg/L[d]	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/ft^2	Copper mg/ft^2
BH-1	0	8.45	2.85					
BH-2	0	8.66	3.99					
BH-3	68	8.78	3.22					
BH-4	0	8.50	2.53	160	6.20	62.3	477	194
BH-5	0	8.66	2.89	268	5.89	80.3	799	249
BH-6	0	8.58	2.73					
BH-7	44	8.64	4.10					
BH-8	1,100	8.75	4.21					
BH-9	860	8.45	2.15	1,440	5.32	82.6	7,160	253
BH-10	868	8.44	3.31	1,540	5.25	90.0	7,470	279
BH-11	790	8.61	3.34	1,340	5.78	84.2	6,620	262
Blank 1	988	7.42	0.06					
Blank 2	716	7.72	0.014					
Results	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/L	pH S.U.	Copper mg/L	Total Solids mg/ft^2	Copper mg/ft^2
Average	418	8.44	2.72	949	5.69	79.9	4,510	248
Std. dev.	462	0.40	1.34	675	0.40	10.5	3,540	32.1

(a) Total pollutant per ft^2 calculated from [(discharge line flow, 2.9 gpm) (3.785 1/gal) (pollutant conc. in discharge line, mg/L) + (ion exchange flow, 2.6 gpm) (3.785 L/gal) (pollutant conc. in line to ion exchange, mg/L)]/the processing rate, ft^2/min.
(b) Total solids were measured using EPA Method 160.2.
(c) pH was measured using EPA Method 150.1; S.U. = standard unit.
(d) Copper was measured using EPA Method 200.7.

TABLE 10. STATISTICAL ANALYSIS OF RESULTS

		Total Solids mg/ft²	Copper mg/ft²
EC Process	Average	23,800	324
	Std. dev.	22,800	73.6
BH Process	Average	4,510	248
	Std. dev.	3,540	32.1
Difference in Averages[(a)]		19,300	76
% Reduction in Averages		81%	23%
Test Statistic	t-value	1.85	2.14
Effect of BH Process[(b)]	—	Significant decrease	Significant decrease

(a) The differences shown are median values.
(b) Based on level of significance of 0.05 (i.e., a 90% confidence level), t-values are compared to a t critical of 1.833. This analysis takes into account the standard deviations.

ECONOMICS

The economic assessment shows the costs for replacing the original electroless copper system with the new carbon black dispersion system and is based on operating costs, return on investment (ROI), and payback period. The calculations are based on the production rate of 200,000 ft^2 of PWB per year, which is approximately the rate of the current electroless copper system. The BH process cost basis is half a year, running at capacity, i.e., the time it would take to process approximately 200,000 ft^2 of PWB.

Operating Costs

Operating costs include costs for labor, chemicals, water, maintenance, and waste treatment/disposal.

- Labor costs for EC are based on 1 operator working for 2,000 hr at an estimated rate of $25/hr; for BH the basis is 1,000 hr at $25/hr.
- Chemical costs for EC and BH are shown in Table 11. Unit costs were obtained from plant records or the suppliers.

TABLE 11. CHEMICAL COSTS

Description	Annual Chemical Usage (gal)[a]	Unit Cost ($/gal)[b]	Cost ($/year)	Adjusted Annual Cost ($/year)[c]
Electroless Copper				
Acid Cleaner	145	21.70	3,150	3,150
Microetch				
Sulfuric Acid	195	0.08	15.6	15.6
Sodium Persulfate	1,880 lbs	1.00 per lb	1,880	1,880
Activator	2,500	3.35	8,380	8,380
Catalyst				
Pre-dip	15.9	3.35	53.3	53.3
Catalyst	21.8	280	6,100	6,100
Accelerator	393	18.65	7,330	7,330
EC				
Copper	3,950	10.35	40,900	40,900
Sodium Hydroxide	2,250	2.50	5,630	5,630
Formaldehyde	199	6.20	1,230	1,230
Sulfuric Acid	308	0.08	24.6	24.6
Anti-Ox	1,250	11.95	14,900	14,900
Total				89,600
BLACKHOLE™				
Cleaner	41.2	400	16,500	8,250
Conditioner	41.4	400	16,600	8,280
BLACKHOLE™	68.0	595	40,500	20,250
Microetch				
Sodium Persulfate	1,130 lb	1.00	1,130	565
Sulfuric Acid	13.2	0.08	1.06	0.53
Copper Sulfate	50.0 lbs	6.62	331	166
Anti-Tarnish				
CTCS 501	6.60	12.00	79.2	39.6
Sulfuric Acid	3.30	0.08	0.26	0.13
Total				$37,500

(a) From Table 7.
(b) McCurdy Circuits provided data.
(c) Because the BLACKHOLE™ process has a production rate approximately twice that of the electroless copper process, costs will be adjusted to compare ½ year of processing for BLACKHOLE™ to a full year for electroless copper.

- Water costs are based on the water requirements for EC and BH presented in Table 12. McCurdy pays $1.20/1,000 gal for tap water and $24.53/1,000 gal for deionized water.

- No significant difference in energy or maintenance costs was assumed.

- No significant difference in waste treatment/disposal costs between the two processes was assumed.

- Waste treatment labor for the electroless copper process was based on 8 hours per week at $25/hr. According to the McCurdy personnel, the BLACKHOLE™ process requires ⅓ of the labor of the electroless copper process.

Table 13 summarizes the major operating costs as obtained above. As seen in Table 13, BH has lower operating costs than EC in all cost categories that could be obtained from company data. The major savings accrue through lower chemical and labor (time) costs, and the total savings add up to more than 50%.

Return on Investment

BH equipment with the capacity of the system tested at McCurdy Circuits currently costs $212,000 (1992 $$), with an estimated installation cost of $9,000. These and other cost assumptions are included in the economics worksheet tables (Tables 14-16). The costs associated with replacing the original system with the new carbon black system are based on the differences in costs between the two systems or the "extra" cost (or savings) to operate the new system. It is assumed that the new system would be used at capacity to replace the old electroless copper system. Therefore, the economic analysis shown is not representative of that of McCurdy Circuits, where the new system is as yet only operating at about 10% capacity. The capital costs included in the analysis are higher than those of McCurdy Circuits, because theirs was purchased several years ago under testing conditions. The costs reflected in this analysis are more typical of what a new user today might expect to pay.

Table 14 shows the capital cost inputs and outputs used for the return-on-investment calculations. In this table, the tax rate, depreciation, and loan information are assumed based on industry averages. Table 15 presents the numbers used for operating cost calculations that were discussed in the previous section. Table 16 reviews the revenues and cost factors, and details the yearly savings in using the BLACKHOLE™ Technology. Table 17 details return on investment, showing that, with an assumed cost of capital of 15%, the payback period is less than 4 years.

TABLE 12. WATER USE

Description	Tap Water (gal)	D.I. water (gal)
Electroless Copper		
Acid Cleaner	0	2500
Microetch	0	2500
Accelerator	0	2500
Sulfuric acid	0	2500
Anti-Ox	0	2500
Rinses	2,670,000	8,000
Totals	2,670,000	20,500
BLACKHOLE™		
Cleaner	0	625
Conditioner	0	625
Microetch	0	1,250
Anti-Tarnish	0	625
Rinses	670,000	0
Totals	670,000	3,125
Adjusted Totals[a]	336,000	1,560

[a] The BLACKHOLE™ production rate is approximately twice as fast as that of the electroless copper process, therefore, the water totals are adjusted to take this into account. The BLACKHOLE™ adjusted total reflects ½ year of processing, whereas the electroless copper total represents a full year.

TABLE 13. MAJOR OPERATING COSTS

Description	Adjusted Annual Cost[a]: Electroless Copper	Adjusted Annual Cost[a]: BLACKHOLE™	Percent Savings
Chemicals	$89,600	$37,500	58%
Tap Water	3,200	403	87%
D.I. Water	503	38.3	92%
Energy[b]	N/A	N/A	0%
Labor	50,000	25,000	50%
Waste Disposal	N/A	N/A	0%
Waste Treatment Labor	10,000	3,330	67%
Totals	$153,000	$66,300	57%

[a] The BLACKHOLE™ production rate is approximately twice as fast as that of the electroless copper process, therefore the costs are adjusted to take this into account. The BLACKHOLE™ costs reflect ½ year of processing, whereas the electroless copper costs represent a full year.

[b] No significant difference is assumed in energy or maintenance costs for the processes.

TABLE 14. CAPITAL REQUIREMENTS

Input Capital Cost		Output Capital Requirement	
Capital Cost		Construction Year	1
Equipment	$212,000		
Materials	$0	Capital Expenditures	
Installation	$9,000	Equipment	$212,000
Plant Engineering	$500	Materials	$0
Contractor/Engineering	$0	Installation	$9,000
Permitting Costs	$0	Plant Engineering	$500
Contingency	$500	Contractor/Engineering	$0
Working Capital	$1,500	Permitting Costs	$0
Startup Costs	$400	Contingency	$500
		Startup Costs	$400
% Equity	100%	Depreciable Capital	$222,400
% Debt	0%	Working Capital	$1,500
Interest Rate on Debt, %	10.0%	Subtotal	$223,900
Debt Repayment, years	0	Interest on Debt	$0
		Total Capital Requirement	$223,900
Depreciation period	7		
Income Tax Rate, %	25.0%	Equity Investment	$223,900
		Debt Principal	$0
Escalation Rates, %	5.0%	Interest on Debt	$0
		Total Financing	$223,900
Cost of Capital	15.0%		

TABLE 15. DIFFERENCE IN OPERATING COSTS

Marketable By-Products	$0	Operating Labor	
Total $/yr	$0	Operator hrs	(1,000)
Utilities		Wage rate, $/hr	$25.00
Electric	$0	Operating Supplies	$0
Total $/yr	$0	Total $/yr	$0
Raw Materials		Maintenance Costs (% of Capital Costs)	
Chemicals	($52,100)	Labor	2.0%
Water	($3,260)	Materials	1.0%
Total	($55,360)	Supervision (% of O&M Labor)	10.0%
Decreased Waste Disposal		Overhead Costs (% of Operating	
Reduced Waste, gal	$0	& Maintenance [O&M] Labor + Super.)	
Offsite Fees, %	$0	Plant Overhead	25.0%
Labor Cost, $	$6,670	Home Office	0.0%
Transportation, $	$0	Labor Burden	28.0%
Storage Drums, $	$0		
Total Disposal Costs, $	$6,670		

TABLE 16. REVENUE AND COST FACTORS

Operating Year Number Escalation Factor	1.000	1 1.050	2 1.103	3 1.158	4 1.216
Increased Revenues					
Increased Production		$0	$0	$0	$0
Marketable By-Products		$0	$0	$0	$0
Annual Revenue		$0	$0	$0	$0
Operating Savings (numbers in parentheses indicate net expense)					
Raw Materials		$58,128	$61,034	$64,086	$67,290
Disposal Costs		$7,004	$7,354	$7,721	$8,107
Maintenance Labor		($4,641)	($4,873)	($5,117)	($5,373)
Maintenance Supplies		($2,321)	($2,437)	($2,558)	($2,686)
Operating Labor		$26,250	$27,563	$28,941	$30,388
Operating Supplies		$0	$0	$0	$0
Utilities		$0	$0	$0	$0
Supervision		$2,161	$2,269	$2,382	$2,502
Labor Burden		$6,656	$6,988	$7,338	$7,705
Plant Overhead		$5,942	$6,240	$6,552	$6,879
Home Office Overhead		$0	$0	$0	$0
Total Operating Savings		$99,179	$104,138	$109,345	$114,812

TABLE 17. RETURN ON INVESTMENT

Construction Year Operating Year	1	1	2	3	4
Book Value	$222,400	$177,920	$142,336	$113,869	$91,095
Depreciation (by straight-line)		$22,240	$22,240	$22,240	$22,240
Depreciation (by double DB)[(a)]		$44,480	$35,584	$28,467	$22,774
Depreciation		$44,480	$35,584	$28,467	$22,774
Cash Flows		$0	$0	$0	$0
Revenues		$99,179	$104,138	$109,345	$114,812
+ Operating Savings		$99,179	$104,138	$109,345	$114,812
Net Revenues		$44,480	$35,584	$28,467	$22,774
− Depreciation		$54,699	$68,554	$80,878	$92,038
Taxable Income		$13,675	$17,138	$20,219	$23,010
− Income Tax		$41,024	$51,415	$60,658	$69,029
Profit after Tax		$44,480	$35,584	$28,467	$22,774
+ Depreciation		$85,504	$86,999	$89,125	$91,802
After-Tax Cash Flow					
Cash Flow for ROI	($223,900)	$85,504	$86,999	$89,125	$91,802
Net Present Value	($223,900)	($149,549)	($83,764)	($25,163)	$27,325
Return on Investment		−61.81%	−15.71%	8.15%	20.84%

(a) DB = declining balance.

QUALITY ASSURANCE

A Quality Assurance Project Plan (QAPP) (Battelle, 1991) was prepared at the outset of the project to outline testing, sampling, and analysis procedures. Testing and sampling were carried out according to the QAPP with the following exceptions. The composite sampling time of the BLACKHOLE™ process line was reduced from the 150 minutes specified in the QAPP to 10 minutes. Due to the limited processing times of the carbon black process employed at McCurdy Circuits, sampling times also were limited. Because the system reaches steady-state quickly and there is little variability in the continuous process, a 10-minute sampling time was adequate. The data support this by the close agreement of the copper readings between samples. The sample time of the electroless copper line also was reduced. The QAPP estimated a sample time of 150 minutes to cover 5 line cycle times. Because the EC line processes a rack every 17 minutes, the EC composite sample time was reduced to 90 minutes to cover 5 cycles.

Analysis of the samples was carried out according to the standard procedures outlined in the QAPP. Duplicates and matrix spikes were analyzed as shown in Tables 18 and 19. The desired precision

TABLE 18. ACCURACY DATA FOR ANALYTICAL RESULTS

Parameter	Sample No.	Regular Sample mg/l	Matrix-Spike Level mg/l	Matrix-Spike Measured mg/l	Accuracy Percent Recovery
Copper	EC-2S	0.375	0.96	1.16	81
Copper	EC-1S	0.212	0.76	0.84	83
Copper	BH-B1	0.060	0.58	0.55	85
Copper	BH-B2	0.014	0.52	0.47	87

TABLE 19. PRECISION DATA FOR ANALYTICAL RESULTS

Parameter	Sample No.	Regular Sample mg/l	Duplicate mg/l	Precision Percent	Method Blank
Copper	BH-4S	2.53	2.51	0.8	<0.003
Total Solids	BH-5I	268	276	2.9	<40
pH	BH-4S	8.489	8.489	0	-
Copper	EC-4I	47.6	47.3	0.6	<0.003
Total Solids	EC-5C	400	408	2.0	<40
pH	EC-4I	3.398	3.398	0	-

of 10% was achieved for duplicate analysis in this project. The QAPP called for an accuracy of 90 to 110% recovery for copper in the matrix spikes, which was not achieved. The results are still considered valid at 80 to 90% recovery because they are being used as comparison values. The percent recovery achieved was below 100%. Therefore, the project planners underestimated the waste reduction potential, but not significantly.

The QAPP detailed procedures for analyzing samples for formaldehyde. Table 20 shows the results of the formaldehyde and, contrary to expectation, formaldehyde was present in the samples from the BH process even though none of the BH formulations contain formaldehyde. The formaldehyde could be from field contamination (no field blanks were taken for formaldehyde) or could be an interferant. Compounds in publicly owned treatment works (POTW) samples are known to result in interference and to give a false positive for formaldehyde (EPA Method 8315A). Thus, no conclusions can be drawn from the formaldehyde analysis. The waste reduction assessment for formaldehyde is therefore based on the chemical formulation information from the plant records.

TABLE 20. FORMALDEHYDE ANALYSIS RESULTS

	Sample Identification	Laboratory Results
<u>Electroless Copper</u>	EC-2C	4.4
	EC-1C	1.9
<u>BLACKHOLE™</u>	BH-3S	BDL
	BH-6S	0.06
	BH-10S	1.5
	BH-10I	2.1

BDL: Below Detection Limit

SECTION 5

REFERENCES

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APPENDIX A

BLACKHOLE™ TECHNOLOGY INFORMATION

BLACKHOLE® TECHNOLOGY:

the environmentally safer, proven alternative to electroless

MacDermid's innovative BLACKHOLE Technology can help you improve the quality of the interconnects in your printed wiring board through-holes.

BLACKHOLE TECHNOLOGY Conveyor System Process II Sequence
BLACKHOLE Clean 110 C
Rinse
BLACKHOLE Starter C
Dry
Rinse
BLACKHOLE Condition 115 C
Rinse
BLACKHOLE Starter C
Heated Dry
Rinse
Microclean
Rinse
BLACKHOLE Antitarnish
Rinse
Dry
Imaging or Panel Plate

Quality Interconnects

BLACKHOLE Technology provides for direct bonding between the foil copper and the electrolytic copper plating. Since both have similar molecular structures, the bond is especially strong. That means fewer risks of defects caused by separation and surface adhesion problems.

Environmentally friendlier

Compared to the electroless copper process, the BLACKHOLE bath uses no formaldehyde, no palladium, no stabilizers, and minimal complexors. That's safer for the environment and your employees.

Less hazardous waste

BLACKHOLE Technology takes an innovative approach to hazardous waste by simply not producing a significant amount in the first place. In many cases the cost of waste treatment and disposal can be cut up to 30% compared to electroless copper. Also, BLACKHOLE Technology uses as much as 50% less water, so there's less water less contaminants to waste treat.

PRODUCTION-PROVEN ELECTRO·

a horizontally automated, fast and reliable through-hole plating process.

Conveyorized BLACKHOLE Technology increases your process control through automation. Now you get quality through-holes and increased through-put.

See for yourself what the Conveyorized BLACKHOLE Technology has to offer.

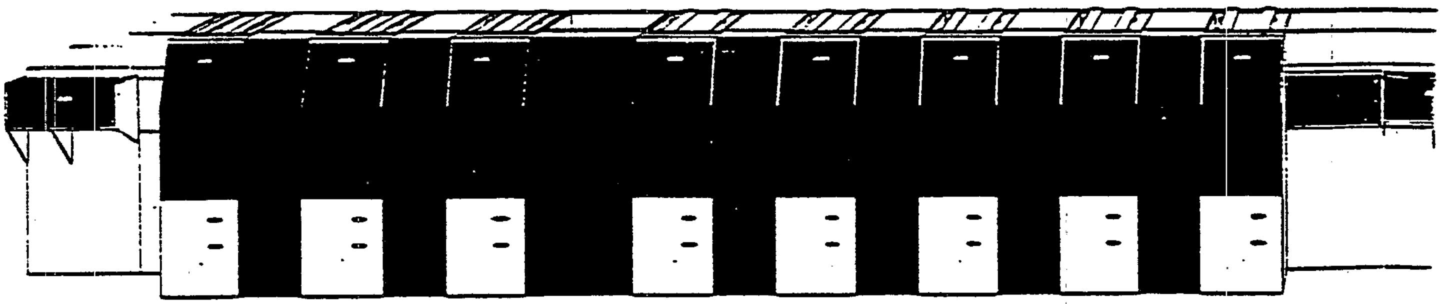
Conveyorized BLACKHOLE Technology consists of two horizontal conveyor systems working in tandem: the flood/immersion unit where the BLACKHOLE chemistries are applied; and the Post-BLACKHOLE Unit which removes the BLACKHOLE chemistries from all foil copper surfaces and preps the board for imaging.

Fully automated
The BLACKHOLE conveyor system* features a remote-control NEMA electrical console, as well as touch control pads and computer-ready electronics for smooth, continual operation.

No racking, no dipping, no dunking
Say good-bye to messy and time consuming batch processing. Since the system is horizontally configured, it significantly reduces materials handling. And because it is automated, the potential for human error is reduced.

Easier process control
Conveyorized BLACKHOLE Technology is based on non-dynamic chemistry, resulting in simplified process control. For example, the single component BLACKHOLE carbon black bath requires monitoring only for pH and solids content.

Higher throughput
The BLACKHOLE Process II conveyor system can produce up to 120 completed panels per hour, based on 18" x 24" boards with 2 inch spacing, and a conveyor speed of about 3.4 feet per minute.



BLACKHOLE Flood/Immersion Unit

*The equipment illustrated is manufactured by Advance Systems, Inc., Phoenix, Arizona

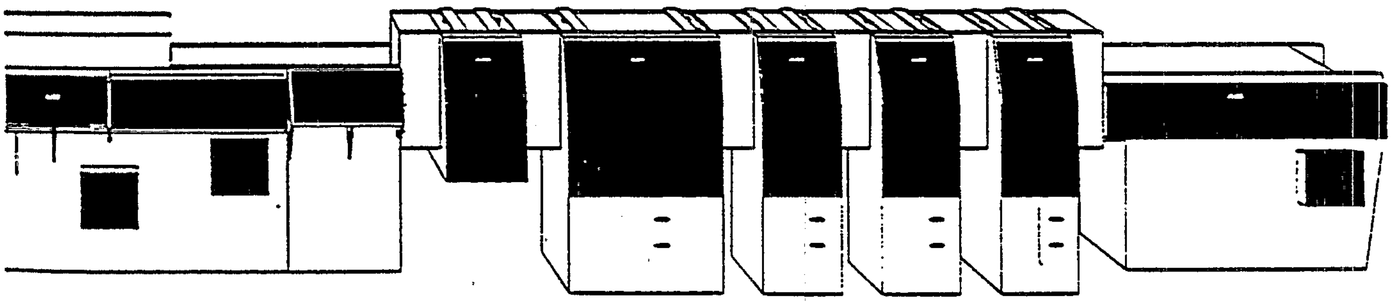
LESS COPPER ALTERNATIVE:

Excellent integration with contiguous processes
Conveyorized BLACKHOLE Technology integrates very well with other horizontal pre- and post-BLACKHOLE processes. This contributes to an exceptionally smooth product flow from start to finish.

Uniform application
Horizontal automation provides consistent and uniform application of the BLACKHOLE chemistries to all surfaces of the through-hole. Automation also assures that every board is exposed to the same process conditions.

Reduced floorspace
The entire BLACKHOLE conveyor system takes up approximately 39 feet (11.9 meters) of floorspace – less than the footprint of an average electroless copper setup. Conveyorized BLACKHOLE Technology frees up a significant amount of floor-space for more productive uses.

Lower operating costs
Conveyorized BLACKHOLE can save money in several ways. Fewer chemicals, in smaller amounts, means less floor space devoted to inventorying large quantities of chemicals. Water usage is drastically reduced. And because you produce less hazardous waste, less is spent on waste treatment and disposal.



Post-BLACKHOLE/Pre-Imaging Unit