April 1998

EPA 744-R-98-002

Alternative Technologies for Making Holes Conductive

Solutions for Printed Wiring Board Manufacturers

Alternative Technologies for Making Holes Conductive

Cleaner Technologies for Printed Wiring Board Manufacturers

This document was produced by Microelectronics and Computer Technology Corporation under grant #X-824617 from EPA's Design for the Environment Branch, Economics, Exposure, & Technology Division, Office of Pollution Prevention and Toxics. Funding was provided through EPA's Environmental Technology Initiative Program.

Acknowledgments

This document was prepared by Abt Associates Inc., Cambridge, MA, for Microelectronics and Computer Technology Corporation, as part of the collaborative Design for the Environment Printed Wiring Board Project. This document is based primarily on the full project report, *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Making Holes Conductive (CTSA),* prepared by the University of Tennessee, Knoxville, Center for Clean Products and Clean Technologies, under a grant from the U.S. Environmental Protection Agency. The EPA Project Officer was Kathy Hart of the Design for the Environment Program, in the Economics, Exposure, and Technology Division, Office of Pollution Prevention and Toxics. The CTSA would not have been possible without the assistance of the technology vendors and their customers, who voluntarily participated in the project. The project Core Group provided valuable guidance and feedback throughout the preparation of the report. Core Group members included: Kathy Hart of U.S. EPA; Christopher Rhodes of the Institute for Interconnecting and Packaging Electronic Circuits (IPC); Dipti Singh of U.S. EPA; John Lott of DuPont Electronic Materials; Michael Kerr of Circuit Center Inc.; Gary Roper of McDonald Technologies, Inc.; John Sharp of Merix Corp.; Jack Geibig, Lori Kincaid, and Mary Swanson of the University of Tennessee Center for Clean Products and Clean Technologies; Greg Pitts of MCC; Ted Smith of Silicon Valley Toxics Coalition; and Jim Dee, an independent consultant to the University of Tennessee.

The cover photo—a microsection of a multi-layer printed wiring board through-hole—was provided by IPC.

Contents

Introduction

Printed wiring boards (PWBs) are an intrinsic part of many products in the electronics, defense, communication, and automotive industries. The traditional manufacture of PWBs requires materials and technologies that raise a number of environmental and human health concerns.

Specifically, wet chemical processes such as those used in PWB fabrication are a significant source of hazardous waste and consume large amounts of water and energy. One such wet chemical process is the method used by PWB manufacturers to make PWB through-holes conductive prior to electrolytic plating. The technology most commonly used today to accomplish this function is the electroless copper process. This technology typically employs formaldehyde as a copper-reducing agent and requires large amounts of water and energy. Alternative technologies are available to accomplish the "making holes conductive" (MHC) function; most of them eliminate the use of formaldehyde, reduce water and energy use, and generate less waste.

The potential environmental and cost advantages of the alternatives are beginning to become apparent and have generated strong interest on the part of industry. To date, however, reliable data comparing these alternative technologies have not been available. To address this data gap, the U.S. Environmental Protection Agency (EPA) teamed up with industry experts in the Design for the Environment (DfE) PWB Project. The project partners include:

- Institute for Interconnecting and Packaging Electronic Circuits (IPC)
- University of Tennessee Center for Clean Products and Clean Technologies
- Microelectronics and Computer Technology Corporation (MCC)
- Silicon Valley Toxics Coalition
- suppliers of MHC technologies
- individual PWB manufacturers

For the first time, PWB manufacturers have access to information on the risk, cost, and performance of the alternative technologies for making holes conductive.

The success of the project was due to the active participation and expertise of a diverse group of partners.

The key to the successful completion of this analysis was the active participation of this diverse project team. The project was open to any MHC chemical supplier who wanted to submit a technology, provided they supplied the necessary data. Although every effort was made to include all emerging and existing technologies, not all technologies are represented in this project.

The project team performed a comparative evaluation of seven different MHC technologies. The analysis focused on evaluating human health and environmental risk, performance, and cost. The technologies evaluated were:

- electroless copper
- carbon
- conductive polymer
- graphite
- non-formaldehyde electroless copper
- organic-palladium
- tin-palladium

The results of the complete analysis can be found in the full, two volume project report titled *Printed Wiring Board Cleaner Technologies Substitutes Assessment (CTSA): Making Holes Conductive* (EPA 744-R-97-002a and 002b).

This booklet summarizes the technical information presented in the full project report.

To disseminate the results of the evaluation to as many interested readers as possible, this booklet was developed to summarize some of the key project findings. For more detailed information on any of the results presented in this booklet, please refer to the CTSA. This booklet and the CTSA are intended to provide PWB manufacturers with information that can assist them in making decisions that consider environmental concerns, along with performance and cost, when choosing an MHC technology.

Performance demonstrations provided data on how these technologies work under "real-world" production conditions.

Data for the comparative analyses were based on a workplace practices survey of PWB manufacturers, supplier information, industry trade association information, and in-facility evaluations conducted by the DfE Project team.

Through the on-site evaluations, performance data were collected from the making holes conductive processes of 25 volunteer PWB manufacturing facilities. These evaluations were intended to be a "snapshot" of the technologies in real-world production conditions, rather than a statistically significant analysis. Multi-layer test panels were designed and manufactured to represent industry "middle-of-the-road" technology. Test panels were sent to each test site and were processed through their MHC lines. Subsequent electrical and mechanical tests were done to evaluate the performance of the MHC interconnects.

Risk, cost, and natural resources analyses were based on a model facility that manufactures 350,000 surface square feet (ssf) of PWBs per year.

For each MHC technology, the risk analysis examined occupational health risks, public health risks, ecological hazards, and process safety concerns. This comparative analysis was based on exposures estimated for a model facility, rather than exposures estimated for a specific facility. The cost, energy, and water use evaluations were also comparative analyses based on a model facility.

Alternative technologies perform at least as well as electroless copper if operated according to specifications.

The results of the analyses suggest that when implemented correctly, all of the alternative MHC technologies perform as well or better than the standard electroless copper technology. Test results also indicated that the alternative technologies can reduce costs and pose less risk to human health and the environment.

Question 1

Why Should I Switch to an Alternative Technology for Making Holes Conductive (MHC)?

Until the last decade, virtually all PWB manufacturers used an electroless copper plating process for the "making holes conductive" (MHC) step in PWB manufacturing. This process is used to deposit a thin, conductive layer of copper into the drilled through-holes of multi-layer PWBs prior to electroplating. Although the traditional electroless copper process is a mature technology that produces reliable interconnects, it is also a source of significant environmental and health concerns. Today, many alternatives to electroless copper exist. These alternative MHC technologies are also often referred to as "direct metallization" processes. The potential advantages of switching to an alternative MHC technology include:

- Improved worker health
- Faster production
- Reduced water and energy consumption
- Simplified waste water treatment
- Reduced waste generation

Improved worker health

Eliminating formaldehyde, a probable human carcinogen, has been one of the driving forces behind the development of alternatives to electroless copper. Direct metallization processes don't use formaldehyde. Additionally, some systems are completely enclosed in conveyorized units, further reducing worker exposure to chemicals during operation.

Faster production

The electroless copper line can be a bottle-neck process for PWB manufacturing. As the demand for PWBs increases rapidly, a quicker turn-around time translates into a competitive advantage for PWB manufacturers. Direct metallization technologies can complete the MHC step two to eight times faster than a typical non-conveyorized electroless copper line. Furthermore, alternative processes are relatively easy to "cold start," compared to a two- to three-hour start-up time required for some electroless copper lines.

Most users of alternative MHC technologies see additional improvements in their process efficiency because they spend less time on lab analysis and bath maintenance than with electroless copper. Some users attribute this change to the automation of tank pump-outs, chemical additions, and other bath maintenance tasks that may be reduced by some direct metallization processes. Other users credit the reduced time to bath compositions that can operate in a wider process window and are easier to analyze.

Reduced water and energy consumption

The typical electroless copper process line consumes a substantial amount of water. It may include 17 or more tanks, depending on rinse configurations. Energy is required for heated baths, pumps, air blowers, and other devices. Direct metallization processes consume significantly less water because they tend to have fewer rinsing steps and greater rinse efficiency. This is particularly true for the conveyorized lines. MHC alternatives are also more energy efficient than electroless copper, primarily because they have a faster cycle time.

Simplified waste water treatment

Chelating agents, such as EDTA, are used to hold metal ions in solution in the electroless copper bath. As a result, these agents inhibit precipitation of metals during waste water treatment. Direct metallization processes don't use chelators. Eliminating chelating agents from bath chemistries may reduce the need for some treatment chemicals and simplify the treatment process.

Reduced waste generation

When compared to an electroless copper process, many facilities have found that direct metallization processes can reduce the copper concentration in their waste water. Some facilities have also reduced the volume of sludge they generate by switching to a direct metallization process.

Question 2

Which MHC Technologies Were Evaluated in the DfE Project?

Alternatives to the traditional electroless copper MHC process are in use in the U.S. and around the world. These direct metallization technologies are wet chemistry processes, consisting of a series of chemical process baths separated by water rinse steps. Direct metallization processes can either be operated in a vertical, non-conveyorized immersion-type mode, or in a horizontal, conveyorized mode. Table 1 lists the processes evaluated as part of the DfE Making Holes Conductive Project:

Bath order and rinse tank configurations were aggregated from information collected from PWB facilities using the different MHC technologies. The figures show the types and sequences of baths in generic process lines, but these may vary in actual lines.

Table 1: Processes Evaluated as Part of the DfE Making Holes Conductive Project

MHC Technology	Equipment Configuration	
	Non-Conveyorized	Conveyorized
Electroless Copper (BASELINE)	✓	✓
Carbon		✓
Conductive Polymer		✓
Graphite		✓
Non-Formaldehyde Electroless Copper	✓	
Organic-Palladium	✓	✓
Tin-Palladium	✓	✓

The electroless copper process was used as the baseline for this analysis.

MHC Processes Evaluated

Following are summaries of each MHC technology evaluated. Each summary includes generic process steps, typical bath sequences, and equipment configurations available.

Typical Steps for an Electroless Copper Process

Cleaner/ Conditioner → Microetch → Predip → Catalyst → Accelerator → Electroless Copper → Acid Dip → Anti-Tarnish

In the electroless plating process, a catalyst is applied to the hole surfaces to enable plating at the catalyst sites during the electroplating process.

In direct metallization processes, low conductivity material is deposited on the hole surfaces.

Electroless copper has been the standard MHC method used in the manufacture of double-sided and multi-layered boards, and it was used as the baseline for the DfE analysis. A palladium/tin colloid is adsorbed onto the through-hole walls, and then acts as the catalyst for the electroless plating of copper. The autocatalytic copper bath uses formaldehyde as a reducing agent in the principle chemical reaction that applies a thin, conductive layer of copper to the nonconducting barrels of PWB through-holes. The process is typically operated in a non-conveyorized mode, although conveyorized systems are also available. Electroless copper processes are compatible with all types of substrates and desmear processes.

Several chemical manufacturers market electroless copper processes for use in MHC applications. The processes differ slightly in types of chelating agents or stabilizing compounds used, but all are based on the electroless copper process described above.

Typical Steps for a Carbon-based Process

Cleaner → Carbon Black → Air Knife/ Dry → Conditioner → Carbon Black → Air Knife/ Dry → Microetch

Carbon processes utilize a suspension of carbon black particles to deposit a conductive layer of carbon onto the substrate surface. The spherical carbon black particles form an amorphous, or noncrystalline, structure of randomly scattered crystallites, which create a conductive layer. The process is typically operated in a conveyorized fashion, but can be modified to be run in a non-conveyorized mode. It is compatible with all common substrates and, in the conveyorized mode, can be fed directly into a cut-sheet dry-film laminator.

Typical Process Steps for a Conductive Polymer Process

Microetch → Cleaner/ Conditioner → Catalyst → Conductive Polymer → Microetch → Copper Flash

This MHC process forms a conductive polymer layer, polypyrolle, on the substrate surfaces of PWB through-holes. The polymer is formed through a surface reaction during which an immobilized oxidant reacts with an organic compound in solution. The conductive polymer process can be operated horizontally and is compatible with most common substrates as well as traditional etch-back and desmear processes. Because of the potential instability of the polymer layer, the conductive polymer-covered through-holes are flash plated with copper in an acid copper electroplating bath. Flash plating may not be required in instances where hold times between the formation of the polymer and the pattern plating step are minimal.

Typical Process Steps for a Graphite-based Process

Cleaner/ Conditioner → Graphite → Fixer (optional) → Air Knife/ Dry → Microetch

Graphite methods disperse graphite (another form of carbon) onto the substrate surface. Similar to the carbon method, a conditioner solution creates a positive charge on the substrate surface, including the through-holes. Graphite particles are then adsorbed onto the exposed surfaces. Graphite has a three-dimensional, crystalline structure as opposed to the amorphous, randomly arranged structure found in carbon black. This crystalline structure creates a conductive layer covering both the copper and the nonconductive surfaces of the outer layer and interconnects. A copper microetch removes the unwanted graphite from the copper surfaces, leaving a conductive, graphite layer on the glass and epoxy surfaces of the vias.

The graphite process typically is operated in a conveyorized mode but can be modified for non-conveyorized applications.

Typical Steps for a Non-Formaldehyde Electroless Copper Process

Cleaner/ Conditioner → Microetch → Predip → Catalyst → Post-dip → Accelerator → Electroless Cu/Cu Flash → Anti-Tarnish

This process is a vertical, non-conveyorized immersion process that allows the electroless deposition of copper onto the substrate surfaces of a PWB without the use of formaldehyde. The process uses hypophosphite in place of the standard formaldehyde as a reducing agent in the electroless copper bath. The hypophosphite electroless bath is not autocatalytic, which reduces plate-out concerns, and is self-limiting once the palladium catalyst sites have been plated. Once a thin layer of copper is applied, the panel is placed under an electrical potential and electroplated while still in the bath to increase the copper deposition thickness.

This non-conveyorized immersion process is compatible with all substrate types but requires an etchback process prior to desmear.

Typical Steps for a Palladium-based Process

Cleaner/ Conditioner → Microetch → Predip → Conductor or Catalyst → Postdip or Accelerator → Acid Dip

Two types of alternatives use dispersed palladium particles to catalyze non-conducting surfaces of PWB through-holes: organic-palladium and tin-palladium. In both of these processes, the palladium particles are adsorbed from solution directly onto the non-conducting substrate, creating a conductive layer that can be electroplated with copper. Palladium particles dispersed in solution tend to agglomerate unless they are stabilized through the formation of a protective layer, or colloid, which surrounds the individual palladium particles.

The **organic-palladium** process uses a water-soluble organic polymer to form the colloid around the palladium particles. This protective layer surrounds the individual palladium particles, preventing them from agglomerating while in solution. After the particles have been deposited onto the board, the protective colloid is removed, making the layer of palladium particles conductive. Organic-palladium can be operated successfully in either conveyorized or non-conveyorized modes. The process is compatible with all common substrates.

Tin-palladium processes use tin to form the colloid with palladium. After the adsorption of the tin-stabilized palladium colloid, the tin is removed, creating a layer of conductive palladium particles on the surface of the substrate. Tin-palladium processes are similar up to the accelerator step but use different methods to optimize the conductivity of the palladium deposit. Tin-palladium can be operated successfully in either conveyorized or non-conveyorized modes.

Direct metallization technologies differ in their ability to increase surface coverage, improve conductivity, and increase plating speed.

Question 3

How May MHC Technologies Affect Worker Health and the Environment?

Through the Design for the Environment PWB Project, ten MHC technologies were evaluated for their risk to human health and the environment. The purpose of the assessment was to compare risks of the traditional electroless copper process to direct metallization processes. Four different components of risk were evaluated:

- Worker health (from inhalation and from skin contact)
- Public health
- Ecological hazards
- Process safety concerns

The assessment was based on exposures estimated for a model facility. Information used to estimate exposures was gathered from a number of sources, including PWB facilities, supplier data, and engineering calculations. The model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors. Risks were evaluated for chronic exposures to long-term, day-to-day releases from the MHC line rather than to short-term, acute exposures resulting from a fire, spill, or other accidental releases.

When estimating risk, exposures were estimated for a "model" facility producing 350,000 ssf/year.

Assumptions and uncertainties are a part of all risk assessments. Some of the major sources of uncertainty in this study included:

- Incomplete identification of all chemicals by some suppliers
- Limited dermal toxicity data available for some MHC chemicals
- Uncertainty in the accuracy of air concentration models used to estimate worker exposure

Uncertainties are part of all risk assessments.

Worker Health Risks from Inhalation

If inhaled, chemicals in some MHC processes may cause employee health problems.

Workers may be exposed to chemicals by breathing air containing vapor or aerosols from non-conveyorized MHC process lines. Inhalation exposure to workers from conveyorized MHC lines is assumed to be negligible because the lines are typically enclosed and vented to the outside. In non-conveyorized lines, however, some MHC chemicals present concerns

Inhalation exposure to workers from conveyorized MHC lines is assumed to be negligible.

because workers may be exposed to inhaled doses that pose potential risks of adverse health effects. Table 2 presents those chemicals that pose a potential risk to worker health as a result of inhalation (i.e., chemicals of concern). This risk is called systematic health risk and does not address cancer-causing chemicals.

Table 2: MHC Chemicals of Concern for Potential Inhalation Risk[a]

Chemical	Electroless Copper	Non-Formaldehyde Electroless Copper	Tin-Palladium
Copper Chloride	✓		
Ethanolamine	✓		✓
2-Ethoxyethanol	✓		
Ethylene Glycol	✓		
Formaldehyde	✓		
Methanol	✓		
Sulfuric Acid	✓	✓	✓
Formic Acid	✓		
Sodium Hydroxide	✓		
Alkene Diol	✓		

[a] For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), all chemicals of concern may not be present in any one product line.

Formaldehyde, found in the electroless copper process, is classified as a "probable" human carcinogen.

Inhalation exposures and therefore cancer risks are negligible for conveyorized systems.

Cancer risk from inhalation was also evaluated. To estimate the inhalation cancer risk of the MHC technologies, the technology must contain cancer-causing chemicals. Only the electroless copper, graphite, and carbon processes contained chemicals that could possibly cause cancer when inhaled, or inhalation carcinogens. None of the other technologies are known to contain inhalation carcinogens, and therefore they do not pose an inhalation cancer risk.

In conveyorized processes, inhalation exposure to these chemicals is assumed to be negligible. The graphite and carbon systems are conveyorized, and there is a conveyorized version of the electroless copper process. Therefore, although these processes may contain possible inhalation carcinogens, they do not pose an inhalation cancer risk.

Chemicals are classified into carcinogen categories based on how strong the evidence is that indicates the chemical does cause cancer. The classification as *probable* human carcinogen means there is some evidence that it causes cancer in humans, but not sufficient evidence to classify it as a human carcinogen. The classification as *possible* carcinogen means that there is sufficient evidence that the substance causes cancer in animals with inadequate or lack of evidence in humans.

Inhalation of formaldehyde in the non-conveyorized electroless copper process may present a cancer risk.

The non-conveyorized electroless copper process uses formaldehyde, a probable human carcinogen. One supplier uses alkyl oxide and cyclic ether. These chemicals have been classified as probable human carcinogens (although cyclic ether is classified in the lesser category of possible human carcinogen by another rating system). The risk estimates for alkyl oxide and cyclic ether indicate low concern for inhalation exposure. For inhalation of formaldehyde, the upper-bound[1] estimate of the potential excess[2] cancer risk may be as high as one in 1,000 or as low as one in 50,000 for line operators. This range reflects the uncertainty and exposure data used in assessing formaldehyde cancer risk. Risks to other workers were assumed to be proportional to the amount of time spent in the process area, which ranged from 3 percent to 61 percent of the risk for a line operator.

Other chemicals in the process are possible carcinogens.

Dimethylformamide, trisodium acetate amine B, and carbon black are found in some MHC processes and are classified as possible carcinogens. Cancer risk for these chemicals was not quantified, since there are not enough data to quantify their carcinogenic potency. Dimethylformamide is used in one of the electroless copper processes evaluated. Trisodium acetate amine B is used in one supplier's electroless copper process. Note that six electroless copper systems were evaluated, representing five different chemical suppliers. Of these, there was only one system that used dimethylformamide and one system that used trisodium acetate amine B. Carbon black is used in the carbon process.

---

[1] "Upper bound" refers to the highest value of a given range of values for a chemical's carcinogenic potency. The laboratory data is statistically analyzed and the results of this analysis are a range of values. As a conservative measure, the highest value is selected.

[2] "Excess" means the estimated cancer risk strictly associated with exposure to the chemical. This is in addition to the background cancer risks associated with other factors including genetic predisposition, diet, expoure to other chemicals outside the workplace, etc.

Worker Health Risks from Dermal Contact

MHC chemicals can enter the body through the skin if workers do not wear gloves.

Dermal (skin) exposure can occur when skin comes in contact with the bath solution while dipping boards, adding bath replacement chemicals, or performing other bath maintenance activities. Although an industry survey suggests that most MHC line operators do wear gloves, the study evaluated the risk to those workers who do not wear gloves. Otherwise, dermal exposure is expected to be negligible. Dermal exposure to workers on non-conveyorized lines occurs from routine line operation and maintenance (i.e., bath replacement, filter replacement, etc.). Dermal exposure to workers on conveyorized lines occurs from bath maintenance activities alone. The carcinogenic risks from dermal exposure to two chemicals, alkyl oxide and cyclic ether, were quantified. The risk estimates for these chemicals indicate low concern for dermal exposure.

Table 3 presents chemicals of concern for potential occupational risk from dermal contact if workers are not wearing gloves. None of the chemicals evaluated in the other alternatives were found to present health concerns from dermal contact.

Table 3: MHC Chemicals of Concern for Potential Dermal Risk[a]

Chemical	Electroless Copper			Non-Formaldehyde Electroless Copper	Organic-Palladium			Tin-Palladium		
	Line Operator		Lab Tech	Line Operator (NC)	Line Operator		Lab Tech	Line Operator		Lab Tech
	NC	C			NC	C		NC	C	
Copper Chloride	✓	✓	✓					✓	✓	✓
Fluoroboric Acid	✓	✓	✓					✓	✓	✓
Formadehyde	✓	✓								
Palladium	✓	✓	✓					✓	✓	✓
Palladium Chloride								✓	✓	✓
Sodium Chlorite	✓	✓		✓						
Stannous Chloride	✓	✓		✓				✓	✓	
Palladium Salt					✓	✓	✓			
Nitrogen H.[b]	✓	✓								
Tin Salt		✓								
Sodium Carboxylate A	✓	✓								

[a] For technologies with more than one chemical supplier (e.g., electroless copper and tin-palladium), all chemicals of concern may not be present in any one product line.

[b] Nitrogen H. = Nitrogen Heterocycle.

NC: Non-conveyorized. C: Conveyorized.

Summary of Worker Health Risks

In summary, alternatives to the non-conveyorized electroless copper process appear to pose lower health risks to workers.

Based on the results of the risk study, it appears that alternatives to the non-conveyorized electroless copper process pose lower occupational risks. This decrease is due primarily to reduced cancer risk to PWB workers when the use of formaldehyde is eliminated. Occupational inhalation risk is assumed to be negligible for conveyorized processes. However, there are inhalation risk concerns for some chemicals in the non-formaldehyde electroless copper, and tin-palladium non-conveyorized processes. In addition, there are also dermal risk concerns for workers who do not wear gloves while working on the conveyorized and nonconveyorized electroless copper, organic-palladium, and tin-palladium processes and the nonconveyorized non-formaldehyde electroless copper process.

There is insufficient information to compare the alternatives among themselves to determine which poses the least risk.

While alternatives to electroless copper appear to pose less overall risk, there is not enough information to compare the alternatives to electroless copper processes among themselves for all their environmental and health consequences. This is because not all proprietary chemicals have been identified, and because toxicity values are not available for some chemicals.

Public Health Risks

Long-term exposure risks are minimal for nearby residents.

Public health risk was estimated for inhalation exposure for people living near a facility. The results indicated that there is very little concern for any of the MHC technologies. For example, the upper-bound excess individual cancer risk for nearby residents from the non-conveyorized electroless copper process was estimated to be from nearly zero to one in ten million. For the conveyorized electroless copper process it was nearly zero to one in three million.

Ecological Risks

Some MHC chemicals are potentially damaging to aquatic ecosystems.

The discharge of waste water from industrial facilities is regulated under the federal Clean Water Act, which limits the concentrations of the chemicals that may be discharged. Facilities discharging to the local sewer or to surface water must have a permit from their federal, state, or local authority. State and local permits may require even stricter limits than are required by the federal government.

A conclusive ecological risk comparison among alternative technologies could not be made because the concentrations of toxics in effluents is not known.

Chemicals were ranked for aquatic toxicity using established EPA criteria.

In this study, ecological risks of MHC technologies were evaluated qualitatively, in terms of aquatic toxicity hazards. Aquatic risk could not be estimated quantitatively because chemical concentrations in MHC line effluents and receiving waters were not available and could not be estimated. However, most of the MHC technologies contain copper compounds that can result in aquatic toxicity problems if discharged to surface waters.

Table 4 presents the number of chemicals with high aquatic toxicity for each MHC technology. For each technology, the table also lists the chemical with the lowest concern concentration (CC), and the bath concentrations of the chemicals with the lowest CC—i.e., the most toxic chemicals. A CC is the concentration of a chemical in the aquatic environment which, if exceeded, may result in significant risk to aquatic organisms. For example, a CC of 0.00002 mg/l means that the chemical may be toxic to aquatic organisms in stream concentrations greater than 0.00002 mg/l. It should be noted that the CC is not a measured quantity. Instead, it is based on the evidence available from existing studies and reflects the uncertainty associated with the data.

Table 4: MHC Chemicals with High Aquatic Toxicity Potential

Alternative	No. of Chemicals[a] with high aquatic toxicity	Chemical with Lowest CC
Electroless Copper	11	copper sulfate 0.00002 mg/l
Carbon	2	copper sulfate 0.00002 mg/l
Conductive Polymer	0	peroxymonosulfuric acid 0.030 mg/l
Graphite	3	copper sulfate 0.00002 mg/l
Non-Formaldehyde Electroless Copper	3	copper sulfate 0.00002 mg/l
Organic-Palladium	2	sodium hypophosphite 0.006 mg/l
Tin-Palladium	8	copper sulfate 0.00002 mg/l

[a] For technologies with more than one chemical supplier (e.g., electroless copper, graphite, and tin-palladium), all chemicals may not be present in any one product line.

Electroless copper processes contain the greatest number of chemicals with high toxicity to aquatic organisms. The most toxic (lowest CC) MHC chemical is copper sulfate, which may be found in five of the MHC technology categories: electroless copper, carbon, graphite, non-formaldehyde electroless copper, and tin-palladium. Note that the table illustrates only the *presence* of these chemicals in the baths. The chemicals' effect on aquatic risk could not be determined, because bath concentrations vary greatly and the concentrations of these chemicals in process effluents vary with differences in treatment systems and operating conditions.

Process Safety Concerns

Workers can be exposed to two types of hazards affecting occupational safety and health: chemical hazards and process hazards.

MHC technologies may present chemical safety concerns.

To evaluate the chemical safety hazards of the various MHC technologies, MSDSs for chemical products used with each of the MHC technologies were reviewed. Table 5 summarizes the hazardous properties listed on MSDSs for MHC chemical products.

Table 5: Hazardous Properties[a] of MHC Chemical Products in their Concentrated Form

MHC Technology	Types of Hazardous Properties Reported on MSDSs[b]
Electroless Copper	flammable, combustible, explosive, fire hazard, corrosive, oxidizer, reactive, unstable, acute health hazard, chronic health hazard, eye damage
Carbon	flammable, corrosive, oxidizer, reactive, acute health hazard, chronic health hazard, eye damage
Conductive Polymer	flammable, corrosive, eye damage
Graphite	unstable, acute health hazard, chronic health hazard, eye damage
Non-Formaldehyde Electroless Copper	flammable, corrosive, oxidizer, reactive, acute health hazard, chronic health hazard, eye damage
Organic-Palladium	unstable, eye damage
Tin-Palladium	flammable, combustible, explosive, fire hazard, corrosive, oxidizer, reactive, sensitizer, acute health hazard, chronic health hazard, eye damage

[a] Information in this table is based on the chemical product in its concentrated form. These properties may not apply to the bath solution as it is used in production. For example, although several chemical products are flammable in their concentrated form, most chemical baths in the MHC process line are non-flammable aqueous solutions.

[b] For technologies with more than one chemical supplier (i.e., electroless copper, graphite, and tin-palladium), all hazardous properties may not be contained in any one product line.

Other chemical hazards can occur because of hazardous decomposition and chemical product incompatibilities.

Most chemicals used in MHC processes can decompose to form potentially hazardous products. All of the MHC processes have chemical incompatibilities that can pose a threat to worker safety. Common chemical incompatibilities are listed on the MSDS and include acids, alkalis, oxidizers, metals, and reducing agents. Some MHC technologies have incompatibilities among chemical products used on the same process line. Users should be familiar with these incompatibilities to avoid potential problems.

Ongoing process safety training is a must.

Work-related injuries from equipment, improper use of equipment, bypassing equipment safety features, failure to use personal protective equipment, and physical stresses that may appear gradually as a result of repetitive motion are all potential process safety hazards to workers. Without appropriate training, the number of work-related accidents and injuries is likely to increase, regardless of the technology used.

Question 4

What Kind of Performance Can I Expect from Direct Metallization Technologies?

The performance of the MHC technologies was evaluated by processing standardized test panels at 25 volunteer PWB facilities in the U.S. and Europe where the technologies were already in use. All test panels were manufactured and drilled at one facility. Three panels were then shipped to each test site for processing through the site's MHC line. The test panel was a 24" × 18" × 0.062" 8-layer PWB produced from B and C stage FR4 materials. The through-holes on the test panels had plated diameters of 0.013", 0.018", or 0.036". After panels went through the MHC process at the test facilities, they were shipped to one central facility, where they were electroplated with 1.0 mil of copper. The panels then underwent microsection and electrical testing to distinguish variability in the performance of the MHC interconnect.

Testing was conducted with extensive input and participation from PWB manufacturers, their suppliers, and PWB testing laboratories. Test sites were recommended by suppliers of the technologies.

For the performance analysis, organic-palladium and tin-palladium technologies were evaluated in one category as "palladium." For cost, risk, and natural resource analyses, these technologies were treated as two separate categories.

Metallurgical microsections of the plated through-holes were evaluated on 18 coupons from each of the 25 sites (450 coupons total). The microsections were examined in the "as received" condition and again after thermal stress. The evaluations examined plating voids, drill smear, average copper plating thickness, resin recession, and inner layer separation.

The study was intended to provide a "snapshot" of the performance of different MHC technologies. It was not intended to substitute for thorough testing at your facility to determine what works best for your operation.

The microsection evaluation demonstrated that direct metallization can perform as well as electroless copper.

- **Plating voids.** There were no plating voids noted on any of the coupons evaluated. The electrolytic copper plating was continuous and very even, with no indication of any voids.
- **Drill smear.** Drill smear negatively impacts inner layer connections to the plated hole wall if not removed. Results are shown in Chart 1.
- **Average copper plating thickness.** Average hole wall thickness varied from 0.95 to 1.7 mils.
- **Resin recession.** No samples failed current specification requirements for resin recession. There was, however, a significant difference in resin recession among test sites, as shown in Chart 1.
- **Inner layer separation.** Over half of the test sites submitted product that did not exhibit inner layer separations on as-received or the thermal stressed

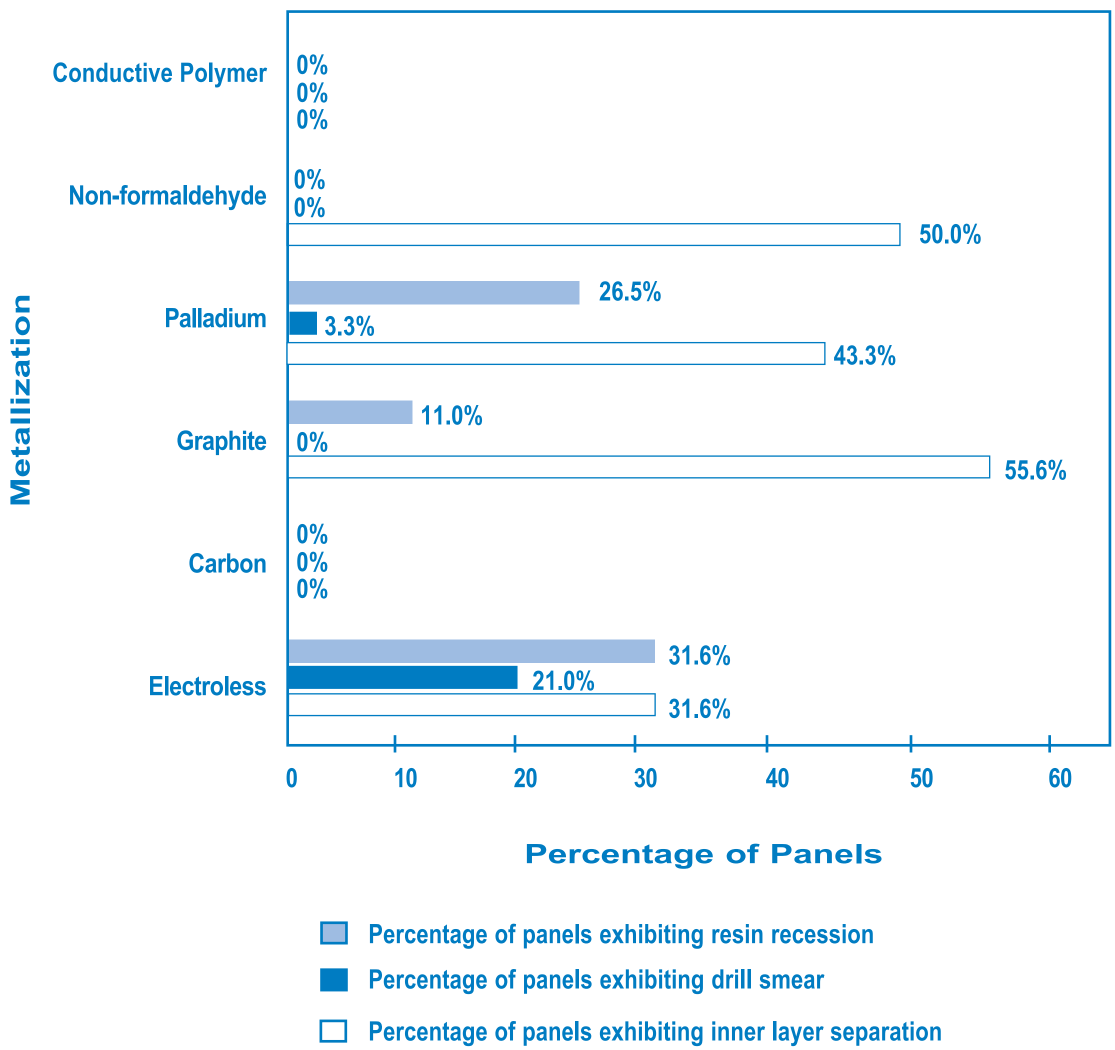
microsections. Some of the product exhibited inner layer separation in the as- received sample which further degraded after thermal stress. Other test sites had product that showed very good interconnect as received and became separated as a result of thermal stress. Results are shown in Chart 1.

Electrical screening tested 1.4 million holes.

Prior to electrical testing, a total of 1,971 coupons each received two resistance measurements to identify defective coupons considered unacceptable for electrical testing because of opens and shorts. A total of 1.4 million holes were tested. One percent (19 coupons) were found to be defective. Opens were caused by voiding, usually within a single via. Shorts were caused by misregistration. The type of MHC technology did not contribute to the shorts.

The number of test sites for each technology ranged from one to ten. Due to the smaller number of test sites for some technologies, results for these technologies could more easily be due to chance than could the results from technologies with more test sites.

Chart 1: Microsection Results—Percentage of Panels Exhibiting Defects



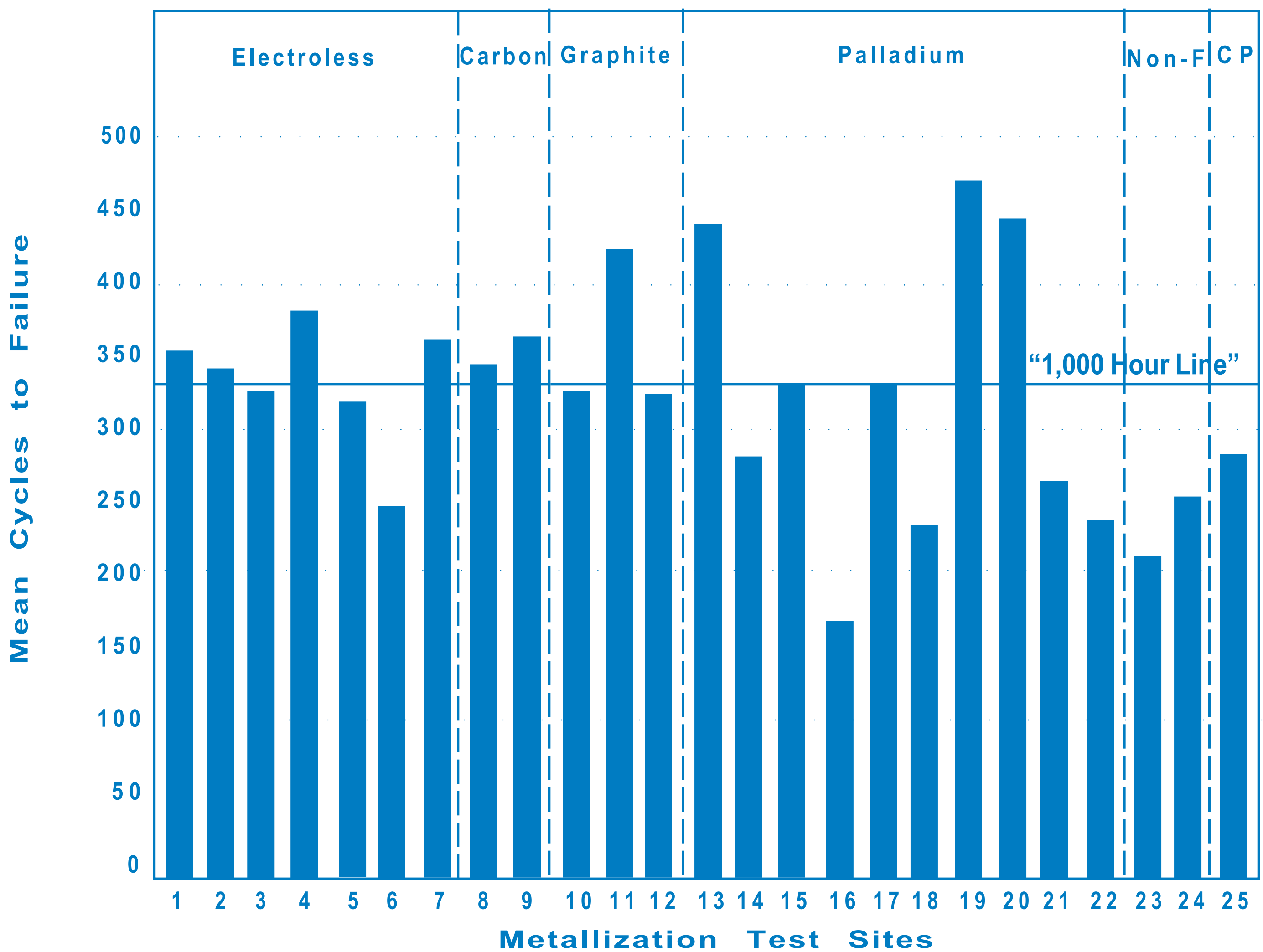
Interconnect Stress Testing

Twelve coupons were subjected to electrical stress testing from each test site, for a total of 300 coupons and 8,400 vias. Electrical stress testing measured plated through-hole cycles to failure, and post separation. The cycles to failure indicate how much stress the individual coupons can withstand before failing to function (measuring barrel integrity). Post separation tests the integrity of the bond between the internal lands (posts) and plated through-hole.

The electrical stress testing demonstrates that all MHC technologies can produce high integrity plated through-holes.

The reference line on Chart 2 identifies the mean cycles to failure (solid line) for all 300 coupons tested (324 cycles). Panels that met or exceeded mean performance are those that measured 324 cycles or higher, respectively. Most test sites had at least one panel that

Chart 2: Electrical Test Results: Cycles to Failure



Non-F = Non-Formaldehyde; CP = Conductive Polymer.

Performance testing indicates that each MHC technology has the capability to achieve levels of performance comparable to electroless copper.

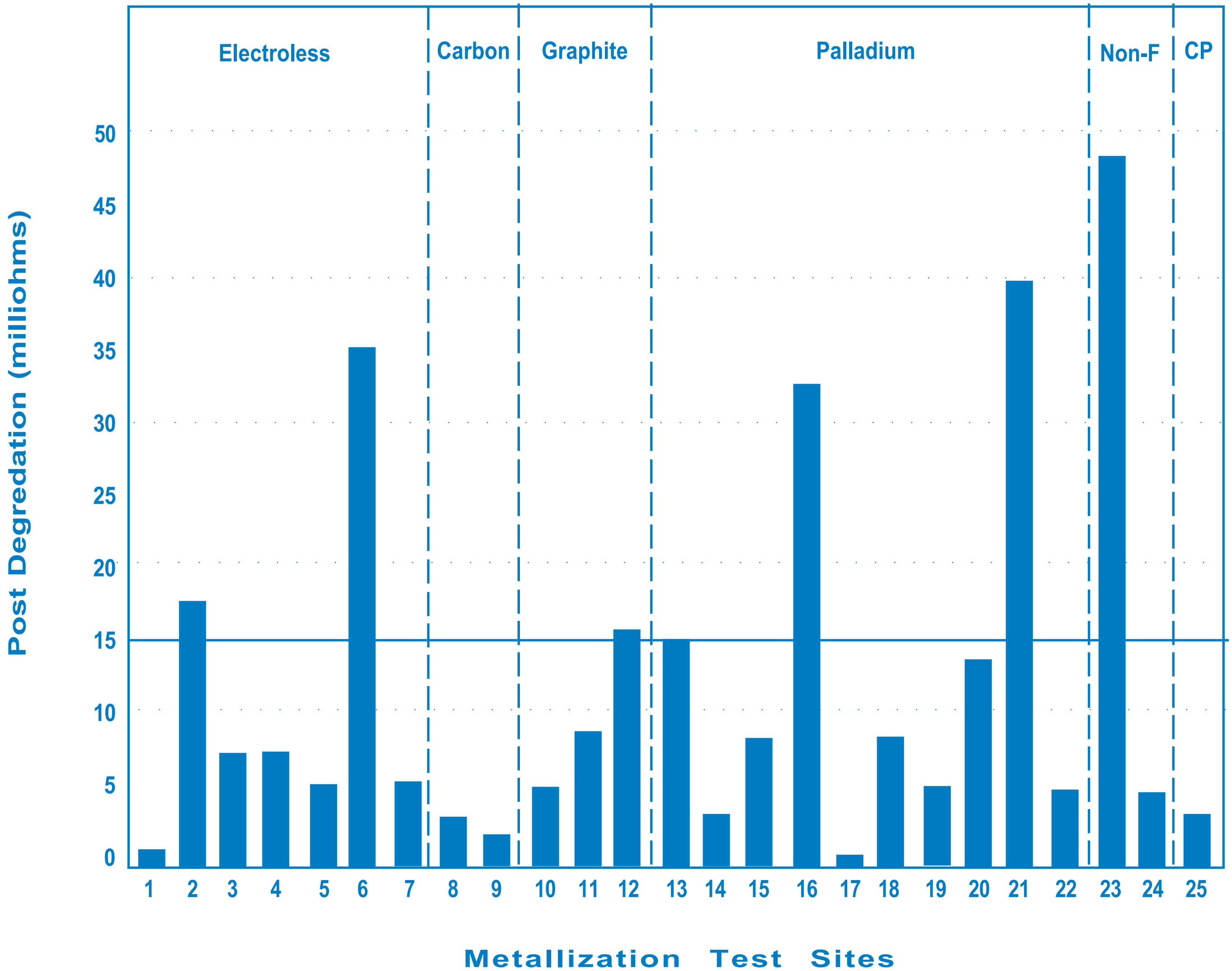
exceeded the 324 cycles. It is interesting to note the variability in performance among sites using the same direct metallization process. These differences highlight the importance of properly installing and maintaining the process.

Post separation was the primary cause for rejection for all MHC technologies tested.

Interconnect Stress Testing also determined post interconnect performance. An industry failure criterion for post separation has not been established. For this study, however, the rejection criterion was based on a 15 milliohm resistance increase (the mean resistance degradation measurement for all 300 coupons tested). The mean resistance degradation of the post interconnect was determined at the time the PTH failed. The readings for the post interconnect for each test site (12 coupons from each site) and for each MHC technology are shown in Chart 3. A mean resistance degradation column above the reference line of 15 milliohms indicates post separation.

Post separation results indicated percentages of post separation that were unexpected by many members of the industry. It was apparent that all MHC technologies, including electroless copper, are susceptible to this type of failure. Variations in performance were attributed to test sites, as opposed to type of MHC technology.

Chart 3: Electrical Test Results: Post Resistance Degradation



Non-F = Non-Formaldehyde; CP = Conductive Polymer.

THE CORRELATION OF RESULTS BETWEEN THE ELECTRICAL AND MICROSECTION TESTS WAS EXCELLENT.

Microsection electrical tests were run independently. When the post separation test results were later compared, they were found to be consistent for 74 of the 75 test panels. To illustrate the consistency of the test results, Table 6 identifies both test methods and their results for post separation detection.

Table 6: Microsection/Electrical Test Data Correlation for Post Separation

MHC Technology	Test Site #	Microsection	Panels Affected	Electrical	Panels Affected
Electroless Copper	1	N	0	N	0
Electroless Copper	2	Y	3	Y	3
Electroless Copper	3	N	0	N	0
Electroless Copper	4	N	0	N	0
Electroless Copper	5	N	0	N	0
Electroless Copper	6	Y	3	Y	3
Electroless Copper	7	N	0	N	0
Carbon	8	N	0	N	0
Carbon	9	N	0	N	0
Graphite	10	N	0	N	0
Graphite	11	Y	2	Y	1
Graphite	12	Y	3	Y	2
Palladium	13	N	0	N	0
Palladium	14	N	0	N	0
Palladium	15	Y	1	Y	1
Palladium	16	Y	3	Y	3
Palladium	17	Y	1	N	0
Palladium	18	Y	2	Y	2
Palladium	19	N	0	N	0
Palladium	20	Y	3	Y	2
Palladium	21	Y	3	Y	3
Palladium	22	N	0	N	0
Non-Formaldehyde Electroless Copper	23	Y	3	Y	3
Non-Formaldehyde Electroless Copper	24	N	0	N	0
Conductive Polymer	25	N	0	N	0

"Y" or "N" (yes or no) denotes whether post separation was detected on any coupon or panel from each test site. The "Panels Affected" column refers to how many of the panels within each test site exhibited post separation. Test Site #17 was the only site where post separation was found in the microsection but not on electrical testing.

Performance variability was related to test sites, as opposed to metallization types.

Technologies tested at more than one site showed good performance at some sites, but performed poorly at others. These findings highlight the importance of properly installing and running the technology, and of good system maintenance practices. The test sites all used the same type of test board. The results will not necessarily be the same for other board materials or constructions. It will, therefore, be important for you to evaluate alternative technologies on your product, preferably by installing test equipment at your facility. Technology vendors may also help you arrange to send your boards to another facility already using the alternative system. Any new MHC technology will need to be customized for your site, processes, chemistries, and products.

Question 5

Will Direct Metallization Reduce My Costs?

A cost analysis was conducted for ten MHC processes. Costs were determined for each technology and equipment configuration (vertical/immersion-type equipment, or horizontal/conveyorized equipment) using information provided by industry surveys, field demonstrations, and computer modeling. The cost model was designed to determine the total cost of processing a specific quantity of PWBs through a fully operational MHC line, in this case, 350,000 surface square feet (ssf). Table 7 summarizes the cost components considered in the analysis.

Table 7: Costs Considered in Analysis

Cost Category	Cost Components
Capital Cost	Primary Equipment
	Installation
	Facility (floor space)
Material Cost	Chemicals
	Water
Utility Cost	Electricity
	Natural Gas
Waste Water Cost	Waste Water Discharge Fee
Production Cost	Transportation of Material
	Labor for Line Operation
	Tank Clean Up
Maintenance Cost	Bath Setup
	Sampling and Testing
	Filter Replacement

Other cost components may contribute significantly to overall costs, but could not be quantified. These include waste water treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs.

The cost model did not estimate start-up costs (other than equipment and installation) for a facility switching to a direct metallization technology, or the costs of other process changes that may be required to implement direct metallization.

The costing was based on a facility producing of 350,000 ssf because this was the average annual throughput for facilities responding to a workplace practices survey.

Conveyorized processes generally cost less than non-conveyorized processes.

MHC Alternatives Cost Less to Use.

Table 8 presents the cost per surface square foot (ssf) of PWB produced for each of the MHC technologies evaluated.

The results show that:

- MHC alternatives are more economical than the non-conveyorized electroless copper process.
- Conveyorized processes generally cost less than non-conveyorized processes.

Costs ranged from $0.51/ssf for the baseline process to $0.09/ssf for the conveyorized conductive polymer process. With the exception of the non-conveyorized, non-formaldehyde electroless copper process, all of the alternatives cost at least 50 percent less than the baseline.

Table 8: MHC Alternative Unit Costs

MHC Alternative	Cost ($/ssf)
Conductive Polymer, conveyorized	$0.09
Tin-Palladium, conveyorized	$0.12
Tin-Palladium, non-conveyorized	$0.14
Electroless Copper, conveyorized	$0.15
Organic-Palladium, non-conveyorized	$0.15
Organic-Palladium, conveyorized	$0.17
Carbon, conveyorized	$0.18
Graphite, conveyorized	$0.22
Non-Formaldehyde Electroless Copper, non-conveyorized	$0.40
Electroless Copper, non-conveyorized (BASELINE)	$0.51

The analysis also revealed that:

- Chemical cost was the single largest component cost for nine of the ten processes.
- Equipment cost was the largest cost for the non-conveyorized electroless copper process.
- The costs of chemicals, production labor, and equipment have the greatest effect on the overall cost results.

The high costs of the baseline process are due primarily to the length of time it took the model facility to produce 350,000 ssf (401 days) using this process. The baseline process took more than twice as long as the next process (183 days for non-conveyorized, non-formaldehyde electroless copper).

Lower Costs Drive PWB Manufacturers Abroad to Switch.

Several suppliers indicated that market shares of the direct metallization processes are increasing more quickly internationally than in the U.S. The cost-effectiveness of an alternative has been the main driver causing PWB manufacturers abroad to switch from an electroless copper process to one of the newer alternatives. In addition to the increased capacity and decreased labor requirements of some of the direct metallization technologies over the electroless copper process, environmental concerns also affected the process choice. For instance, the rate at which an alternative consumes water and the presence or absence of strictly regulated chemicals are two factors that have a substantial effect on the cost-effectiveness of direct metallization processes abroad.

Question 6

Does Direct Metallization Use Less Water and Energy?

Traditional electroless copper processes use a substantial amount of rinse water. As a result, they generate a large volume of waste water that must be treated. Not surprisingly, PWB manufacturers view water conservation as a significant issue. Energy use has also become an important consideration because much of the PWB manufacturing process requires energy-intensive operations, such as heating process baths and electroplating. Businesses are finding that by conserving water and energy, they can cut costs and improve the environment.

Water and energy consumption rates of the MHC process alternatives were calculated to determine if implementing an alternative to the baseline process would reduce consumption of these resources during the manufacturing process.

All of the alternatives consume significantly less water than the traditional electroless copper process.

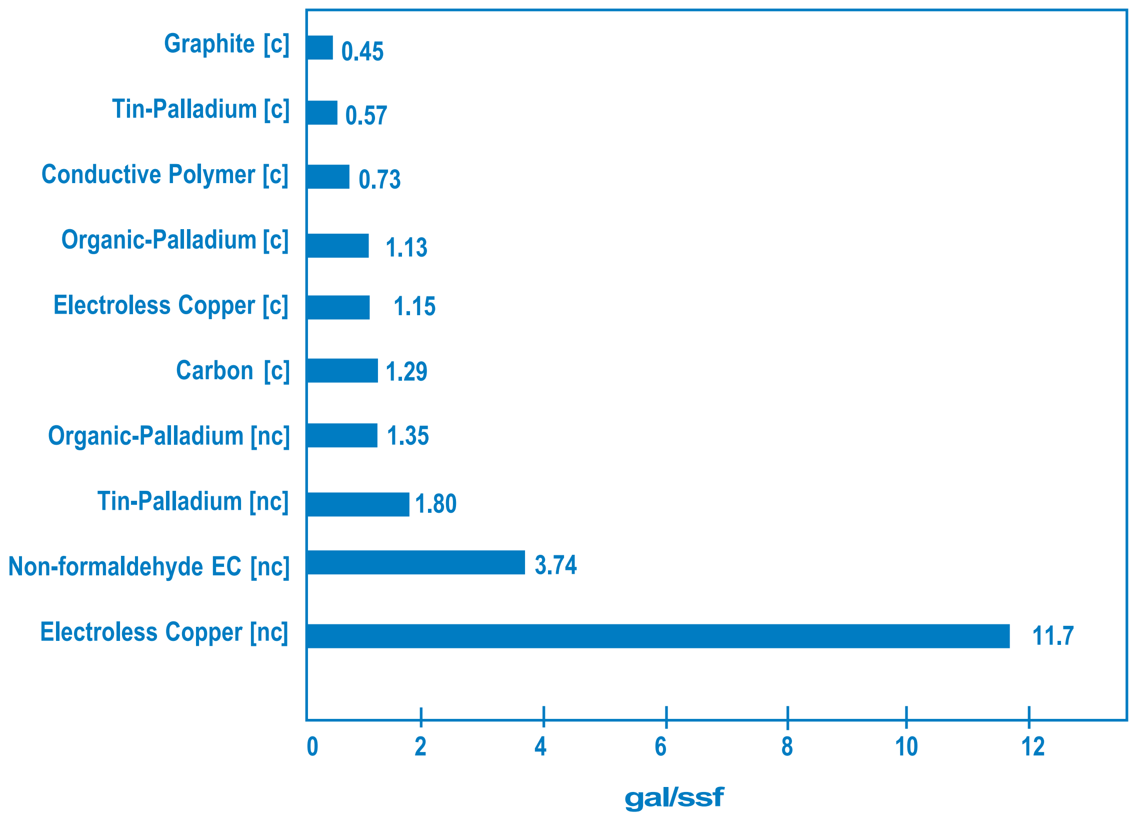
Water consumption rates ranged from 0.45 gal/ssf for the graphite process to 11.7 gal/ssf for the non-conveyorized electroless copper process, as shown in Chart 4. The reduction in water usage is due primarily to the decreased operating time required to process a set number of boards. The conveyorized version of a process typically consumes less water during operation than the non-conveyorized version of the same process. Water is saved because conveyorized processes have fewer rinsing steps and greater rinse efficiencies.

Some companies have taken water conservation a step further by developing equipment systems that monitor water quality and usage to optimize rinse performance. Using countercurrent rinsing and installing flow control devices are other common pollution prevention techniques. These methods further reduce water consumption and, thus, wastewater generation. Further discussion of these and other pollution prevention techniques can be found in the Design for the Environment PWB Project pollution prevention case studies. See Question 10 of this booklet for information on ordering free copies.

Water and energy consumption rates were determined using:
1) the daily water consumption rate and hourly energy consumption rate of each MHC technology, based on industry survey data; and
2) the operating time required to produce 350,000 ssf of PWB, using a computer simulation.

Conveyorized processes typically use less water than non-conveyorized processes.

Chart 4: Water Consumption Rates of MHC Processes



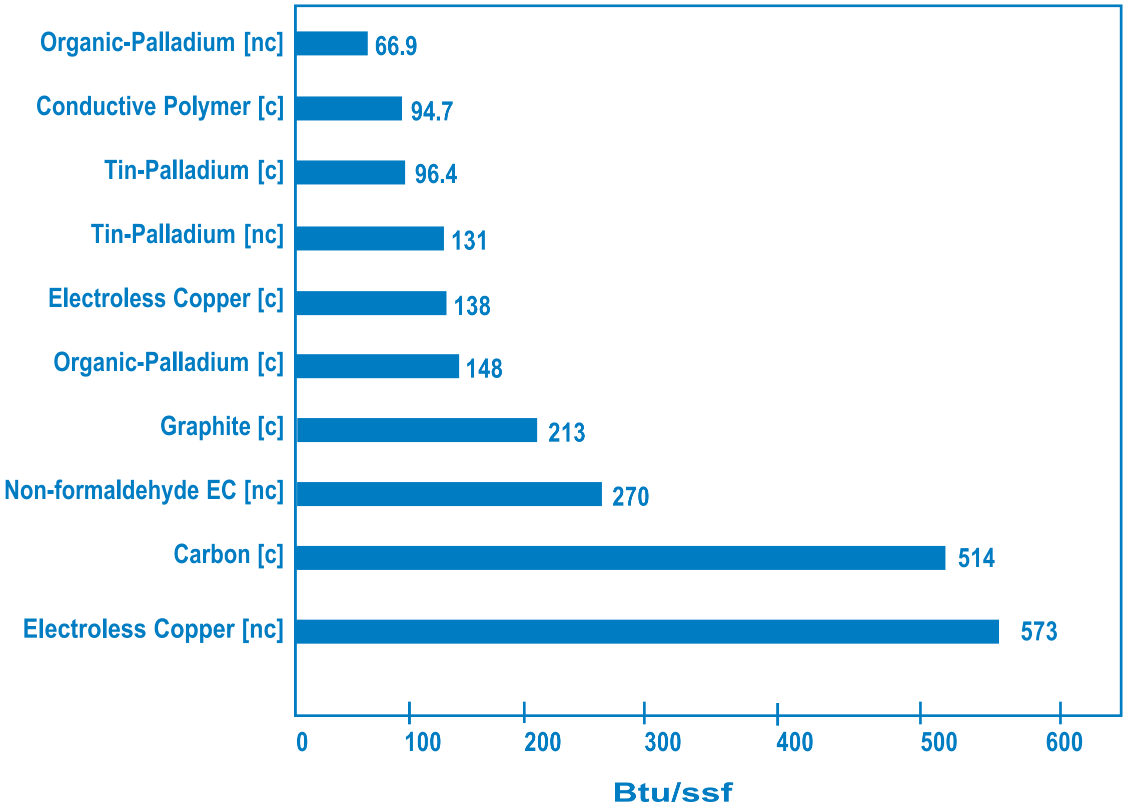
Direct Metallization may simplify wastewater treatment.

Chelating agents, such as EDTA, are used to hold metal ions in solution in the electroless copper bath. As a result, these agents inhibit precipitation of metals during waste water treatment. Direct metallization processes don't use chelators. Eliminating chelating agents from bath chemistries may reduce the need for some water treatment chemicals (those used to break down chelators). Additionally, treatment of the non-chelated waste stream produces less sludge than if chelators were present. For these reasons, direct metallization processes may have advantages over electroless copper in waste water treatment.

All of the MHC alternatives are more energy-efficient than the traditional electroless copper process.

As shown in Chart 5, energy consumption rates ranged from 66.9 Btu/ssf for the non-conveyorized organic-palladium process to 573 Btu/ssf for the non-conveyorized electroless copper process. All of the alternatives use substantially less energy per ssf of PWB produced, with the exception of the carbon technology, which has only a slight decrease (about 10 percent) in energy use from the baseline. For alternatives with both types of orientation (conveyorized and non-conveyorized), the conveyorized version of the process

Chart 5: Energy Consumption Rates of MHC Processes



is typically more energy efficient. Although conveyorized processes typically have higher hourly energy consumption rates than non-conveyorized processes, these differences are more than offset by the shorter operating times required to process an equivalent volume of PWBs. One notable exception is the organic-palladium process. The non-conveyorized version of this process has a low hourly energy consumption rate and a faster operating time. These factors combine to give the non-conveyorized organic-palladium process a lower energy consumption rate than the conveyorized version, and make it the most energy-efficient process evaluated.

Your facility's energy use will also depend greatly on your unique operating practices and energy conservation measures. Implementing simple energy conservation measures can minimize energy use. Such measures can include insulating heated process baths, using thermostats on heaters, and turning off equipment when not in use.

Reduced energy generation required for direct metallization processes results in less harm to health and the environment.

Pollutants released to air, water, and soil resulting from energy generation can be detrimental to both human health and the environment. Consumption of natural gas can result in releases to the air that contribute to odor, smog, and global warming, while the generation of electricity can result in pollutant releases to air and water with a wide range of possible effects. Because all of the direct metallization processes consume less energy than the baseline, they all result in less pollutant releases to the environment from energy production.

Question 7: How Does Direct Metallization Compare to Electroless Copper Overall?

Table 9: Summary results of the evaluation

Alternative	Worker Health Risks *see Question 3*		Environmental Concerns *see Questions 3 and 6*			Performance *see Question 4*	Production Costs *see Quest. 5*
	Inhalation Risk *# chemicals of concern*	Dermal Risk *# chemicals of concern*	Water Use (gal/ssf)	Energy Use (Btu/ssf)	# Chemicals with High Aquatic Toxicity		($/ssf)
Electroless Copper-Non-conveyorized (BASELINE)	10	8	12	573	11, including copper sulfate	Performance for all technologies varied among test sites	0.51
Electroless Copper-Conveyorized	★★	=	★★	★★	=	Comparable or superior	★★
Carbon	★★	★★	★★	=	=	Comparable or superior	★★
Conductive Polymer	★★	★★	★★	★★	★	Comparable or superior	★★
Graphite	★★	★★	★★	★★	=	Comparable or superior	★★
Non-Formaldehyde Electroless Copper	★	★	★★	★★	=	Comparable or superior	★
Organic Palladium-Non-Conveyorized	★★	★	★★	★★	★	Comparable or superior	★★
Organic Palladium-Conveyorized	★★	★	★★	★★	★	Comparable or superior	★★
Tin Palladium-Non-Conveyorized	★	★	★★	★★	=	Comparable or superior	★★
Tin Palladium-Conveyorized	★★	★	★★	★★	=	Comparable or superior	★★

★★ Greatest improvement over the baseline.
★ Some improvement over the baseline.
= Little or no improvement over the baseline.

Question 8

How Can I Make Direct Metallization Work for My Facility?

Manufacturers considering a switch to an alternative process want to know what to expect when they implement the new technology. They want to know what is it like to install, debug, and work with the new system day to day. A change in technology may mean changes in maintenance, lab analysis, and waste treatment requirements. Processes upstream or downstream from the new MHC line may need to be altered. Some of the best sources of information about alternative technologies are those PWB manufacturers who have actually installed and used the systems under real-world operating conditions.

A companion document from the Design for the Environment PWB Project, *Implementing Cleaner Technologies in the Printed Wiring Board Industry: Making Holes Conductive* (EPA document #744-R-97-001), details the specific experiences of 20 manufacturers and seven vendors. The guide presents first-hand accounts of the problems, solutions, time, and effort involved in implementing and operating alternative MHC technologies. Carbon, graphite (two types), palladium (five types), and conductive polymer technologies are discussed in the guide.

Experiences varied among facilities, even among those using the same technology. Some common suggestions emerged for successfully implementing an alternative MHC technology:

✓ Both management and line operators must make a strong commitment to the new technology.

Because there can be major differences between direct metallization and electroless copper processes, line operators need to be willing to accept changes and retraining. Line operators need to be involved during the entire implementation process — installation, start-up, and debugging — to understand the changes that have been made along the way. Management must make a firm commitment to switch to the alternative technology, supporting all phases of implementation.

✓ Take a “whole process view” of implementation.

Process changes upstream and/or downstream may be necessary to optimize the direct metallization process. Both vendors and manufacturers have found that facilities can’t just pull out the electroless line and drop in an alternative process. It is important to look at how the manufacturing process will change overall. One facility using a carbon technology was able to eliminate one of the two acid cleaners from its pre-clean line in the plating process. This change was possible because the new system provided a more consistent surface than their previous process, electroless copper. Another company using a graphite technology found that they needed to adjust the current density on the downstream electrolytic plating operation. Before implementing a new technology, be sure to evaluate your current electrolytic plating quality.

Some facilities found that problems in drilling or desmear operations caused problems in the direct metallization step. Several manufacturers emphasized that fixing these upstream processes is critical to implementing a new MHC technology successfully. Facilities should take a whole process view of the MHC technology installation.

✓ Work closely with your vendor during installation and debugging.

Switching to a new technology may entail retrofitting tanks you already have or installing a completely new conveyorized system. Installation and debugging times vary, even for the same system. Installation of conveyorized systems can range from one week to several months if the facility encounters problems with equipment or other sources. PWB manufacturers emphasized that quality support from the vendor is key to successful implementation. One facility that switched to a non-conveyorized palladium technology completed the retrofit of their old line in one day. At another facility, installation of an entirely new non-conveyorized (vertical) process took one month.

Debugging can take several weeks to several months. Facilities retrofitting existing tanks usually go through a phase during which line operators discover unique qualities of the process that require adjustments, such as analytical frequency, dumping schedules, and interactions with other equipment. Integrating new conveyorized equipment, especially equipment from different manufacturers, can often be the greatest challenge in the debugging process. Automated equipment may take some time to debug, but facilities have found that long-term process efficiency improvements are well worth the up-front effort.

✓ Aggressive preventive maintenance is necessary for most conveyorized (horizontal) systems.

Many of the PWB manufacturers using conveyorized (horizontal) systems experienced some degree of equipment-related difficulties. Problems included plugged nozzles, squeegee rollers collecting solids or not removing enough water, failing controllers and probes, and improperly adjusted water spray pressures. Most facilities spend more time on equipment maintenance than they did when using electroless copper. To minimize downtime, most direct metallization users feel that equipment problems can usually be eliminated by aggressive preventive maintenance. To further avoid potentially costly problems, many PWB manufacturers interviewed also stressed the importance of using high-quality equipment for conveyorized (horizontal) systems.

✓ Implementing a direct metallization process may require changes to waste water treatment.

Nearly all PWB manufacturers interviewed noted that implementing direct metallization resulted in simplified waste water treatment. They no longer have to treat the chelated copper that was present in the electroless copper waste stream. Some facilities noted reduced sludge generation and less copper in the waste water overall.

In contrast, one user of an organic-palladium process could not treat the resulting palladium-containing waste water in its resin-based treatment system. The waste had to be shipped off-site. Another facility had to purchase different waste treatment chemicals due to a change in microetch solution. A change to a peroxide microetch necessitated the addition of sodium metabisulfite to help suppress gas formation. Therefore, carefully evaluate the effects on waste water treatment of any alternative process you are considering. Changes may be necessary.

Question 9

What Steps Do I Take to Switch to Direct Metallization?

✓ Take a look at the boards your facility produces now and what you expect to produce in the future.

Some direct metallization technologies have limitations for parameters such as substrate type or board thickness that can be processed effectively. Knowing your specifications will help identify alternatives that may be appropriate for your facility.

✓ Ask vendors a lot of questions.

Vendors will be the primary source of technical information about alternative MHC technologies and can be a valuable source of information for evaluating your current operation and alternative processes. Here are some of the questions you may want to ask them:

- What type of PWBs have been successfully processed using this technology? Ask about limitations on substrate, hole size, board thickness, and aspect ratio.
- What is the cycle time for this process?
- What chemicals does the process use?
- What are the floor space requirements?
- What are the energy and water requirements?
- Which regulations might apply?
- What health risks are associated with the use of this technology?
- What process or other changes may be necessary?
- What wastes will this system produce?
- How will this system affect waste water treatment?
- Can I speak with other customers about their experience with installation, debugging, and full production?

✓ Evaluate the alternative technology.

The only way you will know if the technology is right for your facility is to test it on your boards. Some vendors may be able to conduct a thorough evaluation of the process in your facility. Alternatively, vendors may be able to arrange to have your boards through-hole plated at a customer's facility where the system is already in place, or at the vendor's testing site.

✓ Do a total cost analysis of switching to the alternative technology.

Consider traditional costs for equipment, chemicals, and labor. But also calculate costs and savings associated with water and energy usage, waste treatment and disposal, monitoring, maintenance, and other activities. Vendors will need to supply a good deal of the cost information.

Computer software can help you analyze the full costs of switching to a new technology. The University of Tennessee has developed a software tool to allow a printed wiring board manufacturer to determine the cost of running different direct metallization processes, as compared to running an electroless copper line. This tool is available through:

University of Tennessee Dept. of Industrial Engineering
Dr. Rupy Sawhney
153 Alumni Memorial Building
Knoxville, TN 37996
ph: 423-974-3333

"P2/FINANCE PWB" is another software tool designed specifically for the PWB industry. This software is more general and helps you evaluate many different investments so that you can choose those that will work best for your facility. For more information, contact:

Tellus Institute
11 Arlington Street
Boston, MA 02116
ph: (617) 266-5400
e-mail: info@tellus.org
internet: http://www.tellus.org

✓ Talk to others who have implemented the direct metallization technologies.

Technology vendors will often provide references for facilities that are currently using the alternative technology.

✓ Tell your customers about your plans to test or implement a new technology.

Some customers may require extensive qualification testing.

Question 10

Where Can I Find More Information about Pollution Prevention in the PWB Industry?

Some excellent resources have been developed on pollution prevention information specifically for the PWB industry. Some of these resources are listed below. Also check with your state technical assistance office to see what other resources may be available.

Documents from the Design for the Environment Printed Wiring Board Project

Alternative Technologies for Making Holes Conductive: Cleaner Technologies for Printed Wiring Board Manufacturers is based on information presented in the full technical report of the DfE PWB Project, titled *Cleaner Technologies Substitutes Assessment: Making Holes Conductive* (EPA 744-R-97-002a and -002b). Other documents developed by the DfE PWB Project include:

Implementing Cleaner Technologies in the PWB Industry: MHC	EPA 744-R-97-001
PWB Industry and Use Cluster Profile	EPA 744-R-95-005
PWB Pollution Prevention and Control: Analysis of Survey Results	EPA 744-R-95-006
Federal Environmental Regulations Affecting the Electronics Industry	EPA 744-B-95-001
Pollution Prevention Workpractices, PWB Case Study 1	EPA 744-F-95-004
On-Site Etchant Generation, PWB Case Study 2	EPA 744-F-95-005
Opportunities for Acid Recovery and Management, PWB Case Study 3	EPA 744-F-95-009
Plasma Desmear, PWB Case Study 4	EPA 744-F-96-003
A Continuous-Flow System for Reusing Microetchant, PWB Case Study 5	EPA 744-F-96-024
Pollution Prevention Beyond Regulated Materials, PWB Case Study 6	EPA 744-F-97-006
Building an Environmental Management System, PWB Case Study 7	EPA 744-F-97-009
Identifying Objectives for Your EMS, PWB Case Study 8	EPA 744-F-97-010

All of these documents, along with additional copies of this booklet, are available free of charge from:

Pollution Prevention Information Clearinghouse (PPIC)
U.S. EPA
401 M Street S.W. (7409)
Washington, DC 20460
phone: 202-260-1023
fax: 202-260-4659
E-mail: PPIC@epa.gov
http://www.epa.gov/envirosense/p2pubs/ppic/ppic.html

Internet Sites

IPC/DfE Printed Wiring Board Project

http://www.ipc.org/html/ehstypes.htm#design

This web site contains DfE Printed Wiring Board Project documents.

Design for the Environment Program

http://www.epa.gov/dfe

This web site also contains DfE Printed Wiring Board Project documents, the document, *Cleaner Technology Substitutes Assessment: A Methodology and Resource Guide*, which describes the basic methodology used in the DfE PWB Project. Click on "Industry Project" to get to the PWB-specific information.

University of Tennessee Center for Clean Products and Clean Technologies

http://eerc.ra.utk.edu/cleanprod/

This site provides information on the Center for Clean Products and Clean Technologies at the University of Tennessee in Knoxville.

Printed Wiring Board Resource Center

http://www.pwbrc.org/

This site was developed by the National Center for Manufacturing Sciences (NCMS) in partnership with IPC, and receives funding from EPA. The site provides PWB industry-specific regulatory compliance and pollution prevention information.

Trade Association, Research, and Academic Institutions

Institute for Interconnecting and Packaging Electronic Circuits (IPC)

2215 Sanders Rd.
Northbrook, IL 60062-6135
phone: 847-509-9700; fax: 847-509-9798
http://www.ipc.org

Microelectronics and Computer Technology Corporation (MCC)

3500 W. Balcones Center Dr.
Austin, TX 78759-5398
phone: 512-343-0978; fax: 512-338-3885
http://www.mcc.com

University of Tennessee Center for Clean Products and Clean Technologies

600 Henley Street, Suite 311
Knoxville, TN 37996-4134
phone: 423-974-8979; fax: 423-974-1838
http://eerc.ra.utk.edu/cleanprod/