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Alternative Technologies for Surface Finishing

Cleaner Technologies for Printed Wiring Board Manufacturers

Office of Pollution Prevention and Toxics

Design for the Environment U.S. EPA

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Office of Pollution
Prevention and Toxics

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This summary document is based on information presented in the project report, *Printed Wiring Board Cleaner Technologies Substitutes Assessment (CTSA): Surface Finishes*, written by University of Tennessee under a grant from EPA. Some information in the CTSA was provided by individual technology vendors and has not been independently corroborated by EPA. The identification of specific products or processes in this document are not intended to represent an endorsement by EPA or the U.S. Government. This summary document has not been through a formal external peer review process.

On the cover is a photograph of the test board used in this project.

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The CTSA would not have been possible without the assistance of the technology suppliers 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 include: Kathy Hart and Dipti Singh of U.S. EPA; Fern Abrams of IPC — Association Connecting Electronics Industries; John Sharp of Teradyne Inc.; John Lott of DuPont Electronic Materials; Jack Geibig, Lori Kincaid, and Mary Swanson of the University of Tennessee Center for Clean Products and Clean Technologies; Greg Pitts of Ecolibrium; Gary Roper of Substrate Technologies, Inc.; Ted Smith of the Silicon Valley Toxics Coalition; and Christopher Rhodes and Holly Evans, formerly of IPC.

Contents

Introduction

The project researched how alternative surface finishes compare to the performance, cost, and environmental and health characteristics of HASL.

The printed wiring board (PWB) is the base that connects components in electronic devices. One of the final steps in the PWB manufacturing process is to provide a surface finish on exposed parts of the board. This surface finish is important for two reasons: it protects the underlying copper from corrosion, and it provides a solderable surface on which to apply the components in subsequent assembly steps.

To date, the industry's standard surface finish has been hot air solder leveling (HASL). This process deposits a layer of tin-lead solder onto exposed portions of the PWB. HASL provides a highly solderable coating, a wide process window in assembly, and a long shelf life. However, many PWB manufacturers and assemblers are re-evaluating their choice of surface finish for boards with fine pitch (small) surface mount components, because the HASL process typically creates a slight crest on pads, rather than the planar surface required for assembly. An additional concern is the worker health and environmental issues associated with lead use. With impending regulations in Europe requiring the use of lead-free materials, market pressures are another consideration for PWB manufacturers.

Several alternative surface finish technologies are available that can provide a planar mounting surface and do not use lead. They range from other metals such as nickel, tin, gold, and silver to organic-based coatings. Although many facilities use these alternative surface finishes, a comprehensive analysis has not been undertaken before to compare the performance, cost, and health and environmental risks associated with them. In response to industry interest for this information, the Design for the Environment (DfE) PWB Project undertook a comparative evaluation of health risk and competitiveness issues for HASL and five alternative surface finishes. The project was a voluntary, cooperative partnership among EPA and industry experts including: PWB industry manufacturers, assemblers, and suppliers; the University of Tennessee Center for Clean Products and Clean Technologies; a public interest group; and other stakeholders. Goals of the project are to:

The Design for the Environment (DfE) PWB Project is a voluntary, non-regulatory partnership among a diverse group of contributors.

- Encourage businesses to incorporate environmental concerns into their decision-making processes, along with traditional parameters of cost and performance, when choosing technologies and products.
- Standardize existing information about surface finish technologies.
- Present information about surface finish technologies not yet in widespread use, so PWB manufacturers and designers can evaluate the environmental and health risks, along with the cost and performance characteristics, of different technologies.
- Encourage PWB manufacturers and designers to follow the example of this project and systematically evaluate other technologies, practices, and procedures in their operations that may affect the environment.

The project team evaluated six different surface finish technologies:

- HASL
- Electroless Nickel/Immersion Gold (Nickel/Gold)
- Electroless Nickel/Electroless Palladium/Immersion Gold (Nickel/Palladium/Gold)

- Immersion Silver
- Immersion Tin
- Organic Solderability Preservative (OSP)

The analysis was intended to represent the use of these surface finishes under "real world" production conditions. To accomplish this, data were collected from several sources. These included performance demonstrations at volunteer PWB facilities, chemical exposure estimates from a survey of workplace practices, waste generation estimates from a survey of pollution prevention practices, and cost estimates from surface finish suppliers.

Performance data were generated by applying surface finishes to standardized test boards at 13 volunteer facilities. Though this arrangement does not yield the type of results that would result from a tightly controlled experiment, it presents a "snapshot" of each technology as they might perform relative to each other under typical facility conditions. The PWBs produced at these facilities then were subjected to accelerated aging, thermal shock, and mechanical shock conditions. An ion chromatography failure analysis was then conducted to determine if the causes of failure for boards that did not pass these tests were related to specific surface finishes.

The human health and ecological risk characterization was based in part on a survey of workplace practices conducted by IPC. From this survey, the typical rate at which workers in a PWB facility are exposed to chemicals used in surface finishes was estimated. When combined with known information about the toxicity of chemicals, EPA was able to estimate the risks to employees working with each surface finish. The ecological risk assessment was based on an estimate of the concentration of chemicals in wastewater, combined with information about the toxicity of the chemicals in the environment.

The costs of each technology were collected from the workplace practices survey, surface finish suppliers, and industry experts. These data then were modeled to represent the costs, energy and water usage, maintenance schedule, and labor needs that might be encountered by a facility that has a throughput rate of 260,000 surface square feet per year (ssf/yr).

This booklet summarizes the key findings of the study. Each question in this booklet highlights a different aspect of the research. The full report, *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Surface Finishes* (EPA 744-R-01•003A and B), contains information that is useful for readers who would like to learn more about each surface finish technology.

Detailed results can be found in the full report. The report, *Printed Wiring Board Cleaner Technologies Substitutes Assessment: Surface Finishes* (EPA 744-R-01-003A and B), contains information that is useful for readers who would like to learn more about each surface finish technology. To download the report, visit:

www.epa.gov/dfe

Question 1

Why should I consider an alternative surface finish?

Many alternative surface finishes appear to demonstrate improvements in worker health and safety, cost, and reduced environmental impacts.

The industry's standard process for applying a surface finish to printed wiring boards (PWBs) has been tin-lead hot air solder leveling (HASL). For some time, this process has been the most accepted and reliable method of preserving solderability. However, many PWB manufacturers are finding that the process has performance and environmental limitations. The solder leveling process typically creates a crest on pads, especially with fine pitch surface mount pads, which can lead to assembly defects. While HASL is still the preferred finish for through-hole PWBs, manufacturers working with surface mount technology (SMT) are looking for surface finish alternatives that can provide a planar surface. In addition, the use of lead in the HASL process can result in workplace health and environmental concerns. Although the benefits may not apply to all of the alternative technologies, there are several reasons why PWB manufacturers are considering alternative surface finishes:

Improved Chemical Safety

None of the alternative technologies are free of risk to workers. However, some of the technologies do not contain as many chemicals that pose flammability, explosiveness, and instability concerns as HASL does.

Improved Worker Health

All technologies using an enclosed conveyorized process have a low estimated risk to workers from inhalation. Several of the technologies have fewer chemicals that pose potential risks through skin contact as well.

Comparable or Improved General Public and Ecological Health

None of the technologies, including the baseline HASL process, appear to present an appreciable risk to the general population outside of PWB facilities under normal conditions (the effects of unexpected spills and fires were not considered in this analysis). With regard to ecological risk, all of the alternative technologies use fewer chemicals that may harm aquatic ecosystems.

Comparable Performance

In the evaluation of the comparative performance of the six surface finishes analyzed, 164 assembled PWBs were subjected to accelerated aging (85°C and 85% relative humidity for three weeks), thermal shock, and mechanical shock conditions. After each exposure, 23 electrical test measurements were recorded for each board. Although some anomalies were identified, these were rarely related to the surface finish applied. A failure analysis using ion chromatography indicated that all five alternative (non-HASL) finishes performed as well as, if not better than, the HASL finish following accelerated aging conditions.

Lower Material Costs

For all but two of the alternative technologies (those involving the precious metals gold and palladium), the chemical inputs are less expensive than those for HASL. In particular, the lower cost is often driven by the thinner surface layer that is required. Lower material demands also may have benefits for society by reducing the impacts associated with the raw material (e.g., metal mining).

Less Water Consumption

The high-pressure rinse used in the HASL process consumes up to 2.5 times more water than a normal rinse. For the alternative technologies that require relatively few rinse steps (Immersion Silver and OSP), water consumption is considerably lower. A decrease in water consumption benefits individual companies by reducing costs associated with obtaining water and processing it as wastewater. Reduced water demand also benefits the general public and the environment by preserving a valuable natural resource.

Question 2

Which surface finishes were evaluated in the DfE Project?

Most technologies can be operated in either a horizontal, conveyorized or vertical, non-conveyorized configuration.

All the alternative surface finish technologies were wet chemistry processes involving a series of chemical process baths and water rinse steps. The processes were operated either in a horizontal, conveyorized process or vertical, non-conveyorized process. Table 2.1 indicates the operation mode for each technology.

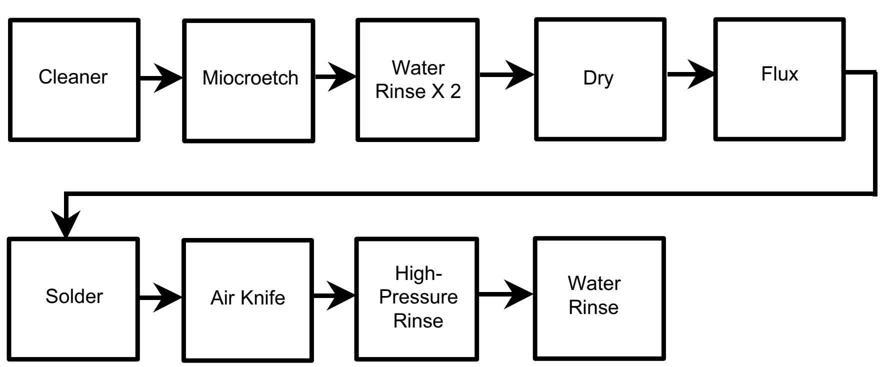
Table 2.1 Surface Finishes Included in the Analysis

Process	Conveyorized	Non-Conveyorized
HASL	✓	✓
Electroless Nickel/ Immersion Gold		✓
Electroless Nickel/ Electroless Palladium/ Immersion Gold		✓
Immersion Silver	✓	
Immersion Tin	✓	✓
OSP	✓	✓

All surface finish suppliers were invited to submit a product as long as they provided all of the data required for the analysis. Because the DfE project is voluntary and the products were not chosen systematically, the results may not be representative of all variants of a technology. Typical steps required for each technology are described below.

Hot Air Solder Leveling (HASL)

HASL is the project's baseline technology.

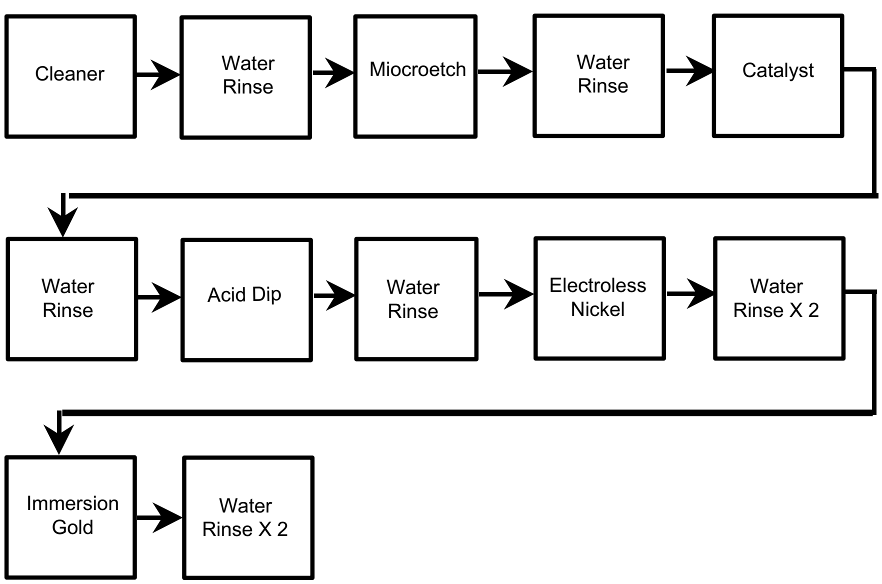


Tin-lead HASL has been the standard surface finishing method used in the manufacture of double-sided and multi-layer boards due to its excellent solderability during assembly. It was considered the baseline for the DfE analysis. During the HASL process, soldermask-coated boards are first cleaned and etched to prepare the contact surfaces for the solder. Following the application of flux to a board, a layer of solder is applied to the copper surfaces by submersing the panel in molten solder. The excess solder is then blown from the board by an air knife, leaving a thin, protective layer of solder on the exposed circuitry.

The process can be operated either in a horizontal, conveyorized mode or as a vertical, non-conveyorized system. Flux selection is critical to the sound operation of the HASL process. The flux is responsible for creating the surface conditions required to achieve a high quality solder deposit on the PWB. Fluxes are available in a variety of formulations with differing characteristics such as viscosity, foam level, acidity, volatile content, and type of activator. The type of HASL flux ultimately selected will depend on the type of chemicals and processes used in previous manufacturing stages, type of solder mask, and the solder deposit characteristics required.

HASL finishes are compatible with surface mount technology (SMT) and typical through-hole components; however, the lack of planarity, or flatness, of the finish makes assembly with fine pitch surface mount components difficult to control. Extended shelf life is not a concern with HASL finished boards, because of the durability of the finish.

Electroless Nickel/Immersion Gold



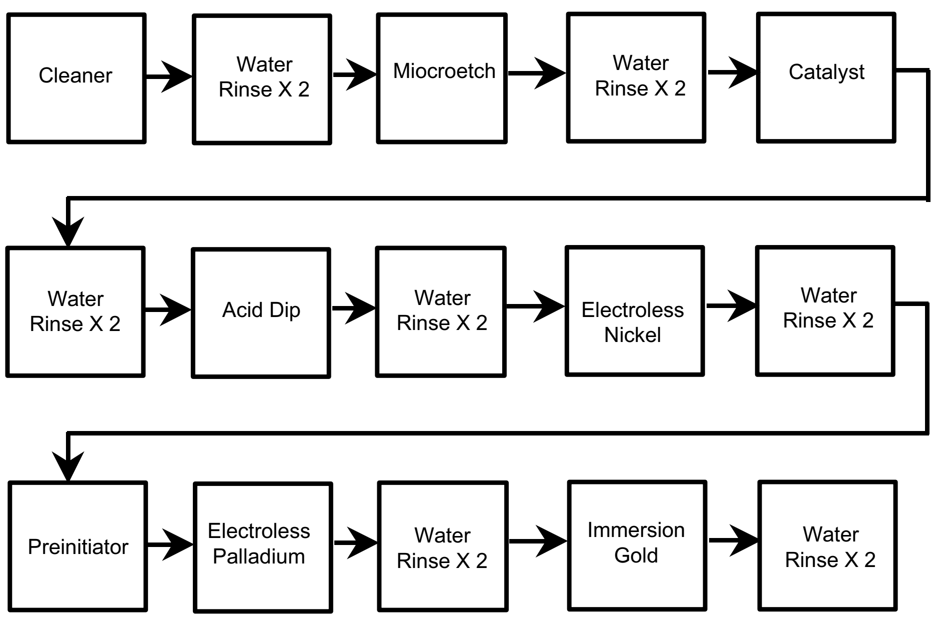
The Electroless Nickel/ Immersion Gold finish consists of a relatively thick layer of nickel followed by a thin protective layer of gold.

The Nickel/Gold process is applied through the deposition of an initial layer of nickel followed by a thin, protective layer of gold onto the exposed copper surfaces of the PWB. Nickel characteristics such as hardness, wear resistance, solderability, and uniformity of the deposit make this a desirable surface finish. The thin layer of immersion gold preserves the solderability of the finish by preventing oxidation of the highly active nickel surface. Nickel/Gold finishes typically can withstand ermal excursions (heating cycles) without losing solderability.

The process is operated in a vertical, non-conveyorized mode. An Electroless Nickel/Immersion Gold finish is compatible with SMT, flip chip, and ball grid array (BGA) technologies, as well as typical through-hole components. The finish is also aluminum wire-bondable. The high plating temperatures and low pH of the Nickel/Gold plating process can be incompatible with soldermasks with high acrylic content; however, soldermasks high in epoxy content are not affected by the plating solutions. Nickel/Gold plated boards have a shelf life of two years or more.

Electroless Nickel/Electroless Palladium/Immersion Gold

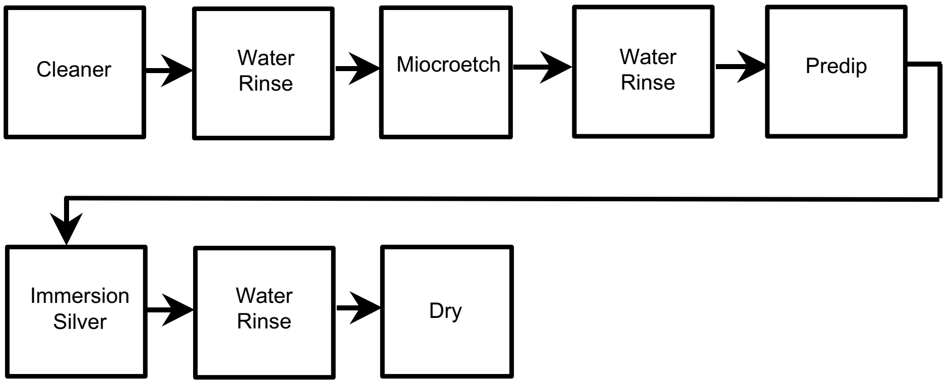
The Electroless Nickel/Electroless Palladium/Immersion Gold finish is similar to the Nickel/Gold finish but has a palladium layer between to provide hardness.



The Electroless Nickel/Electroless Palladium/Immersion Gold process is similar to the Nickel/Gold process, except that it uses a palladium metal layer that is deposited after the nickel layer, and prior to the final gold layer. The palladium layer is much harder than gold, providing added strength to the surface finish for wirebonding and connector attachment, while protecting the underlying nickel from oxidation.

The process can be operated in either a horizontal, conveyorized or a vertical, non-conveyorized mode. (Only the vertical process was evaluated in the DfE study.) Like a Nickel/Gold finish, a Nickel/Palladium/Gold finish is compatible with SMT, flip chip, and BGA technologies, as well as with typical through-hole components. The finish is also both gold and aluminum wire-bondable. The Nickel/Palladium/Gold plated boards have a shelf life of two years or more.

Immersion Silver

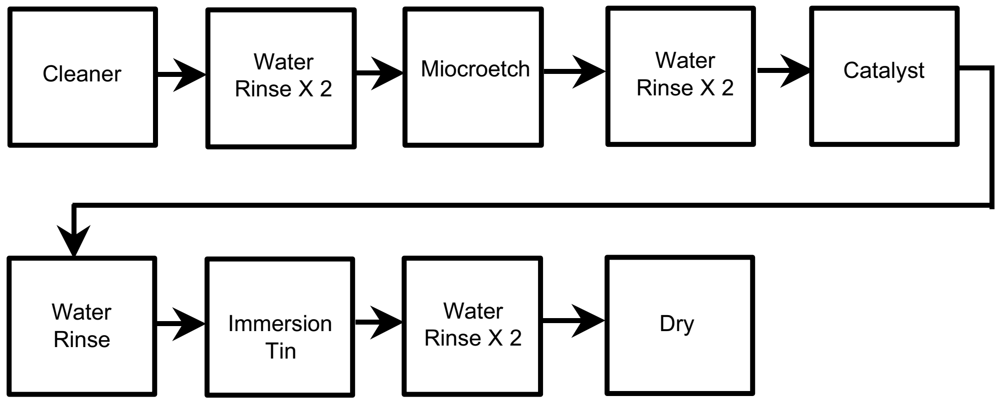


The Immersion Silver finish consists of a silver layer and a protective organic coating.

The Immersion Silver finish is produced by the selective displacement of copper atoms with silver atoms on the exposed metal surface of the PWB. To minimize silver tarnishing, an organic inhibitor is co-deposited to form a hydrophobic layer on top of the silver. The typical thickness of an Immersion Silver finish depends on the chemistry. It can range from 3 to 10 microinches (0.08 to 0.25 microns) thick. There are two chemistries in production; one is operated exclusively as a horizontal, conveyorized process, and the other can be operated either horizontally or vertically. (The DfE study only evaluated the horizontal configuration.) Immersion Silver finishes are compatible with SMT, flip chip, and BGA technologies, as well as typical through-hole components. Silver finishes appear to be compatible with all types of solder masks, can withstand five thermal excursions during assembly, and are anticipated to have a shelf life of at least six months.

The Immersion Tin finish displaces surface copper with a thin layer of tin.

Immersion Tin

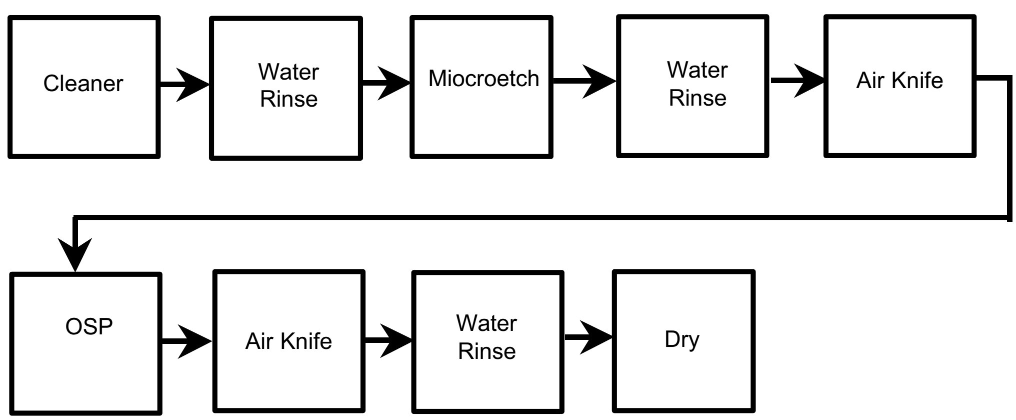


The Immersion Tin process utilizes a displacement reaction between the board's copper surface and stannous ions in solution to reduce a layer of tin onto the copper surfaces of the PWB. The process may be installed as a conveyorized system or in a vertical, non-conveyorized mode. Immersion Tin surfaces are compatible with SMT, flip chip, BGA technologies, and typical through-hole components, but it is not a wire-bondable finish.

There are a number of different Immersion Tin systems available, including those based on methane sulfonic acid, sulfate, chloride, and fluoborate chemistries. Tin surfaces are compatible with all solder masks, have a shelf life of at least one year, and can typically withstand a minimum of five thermal excursions during assembly.

The OSP finish is an organic (non-metal) film that bonds to exposed copper.

Organic Solderability Preservative (OSP)



The OSP finish is an anti-oxidant film applied to exposed copper surfaces that reacts with copper to form an organometallic layer. This coating is nearly invisible, and may be applied either as a thick benzimidazole (4 to 20 microinches / 0.1 to 0.5 microns) or thin imidazole [mono-molecular (30 to 100 angstroms)] layer. The thicker OSP coatings were considered in the DfE analysis. The OSP process typically is operated in a horizontal, conveyorized mode but can be modified to run in a vertical, non-conveyorized mode. OSP processes are compatible with SMT, flip chip, and BGA technologies, and with typical through-hole components, but the OSP finish cannot be wirebonded. OSP surfaces are compatible with all soldermasks and have a shelf life of up to one year.

Question 3

How do alternative finishes compare to hot air solder leveling (HASL) overall?

HASL and the five alternative technologies were evaluated in several categories. Table 3.1 shows a summary of how each performed relative to the baseline technology with respect to worker risk, environmental risk, performance, cost, and resource use. More detailed information on each of these evaluation criteria can be found in subsequent sections of this document.

Table 3.1 Summary of Surface Finish Technologies

Technology (see question 2)	Worker Risk (see question 4)		Environmental Risk (see question 5)	Performance (see question 6)	Cost (see question 7)	Resource Use (see question 8)	
	Inhalation Risk (# of chemicals)	Dermal Risk (# of chemicals)	# of Chemicals with Aquatic Risk Indicator >1	Surface Finish-Related Anomalies	$/260,000 sq.ft.	Water Use (gall/260,000 ssf)	Energy Use (Btu/260,000 ssf)
HASL (NC) BASELINE	1	2	4	=	$94,200	322,000	56,700,000
HASL (C)	✓	=	✓	=	=	✓	✓
Ni/Au (NC)	✗	✗	✓	=	✗	✗	✗
Ni/Pd/Au (NC)	✗	✗	✓	=	✗	✗	✗
Imm. Silver (C)	✓	✓	✓	=	✓	✓	✗
Imm. Tin (C)	✓	✓	✓	=	✓	✓	✗
Imm. Tin (NC)	✓	✓	✓	=	✓	✗	✗
OSP (C)	✓	✗	✓	=	✓	✓	✓
OSP (NC)	=	✗	✓	=	✓	✓	✓

(C) Conveyorized process
(NC) Non-conveyorized process
✓ Indicates improvement over baseline
✗ Indicates a negative change from baseline
= Indicates the alternative is equal to or within 5% of the baseline

Question 4

How may surface finishes affect worker health and safety?

Chemicals in surface finishes can affect workers in PWB manufacturing facilities either when handled or when chemical vapors are inhaled. The DfE risk screening compared the potential risks to workers from using the five alternative surface finishes to those from using HASL. The following types of effects were considered in the analysis:

- Chronic (non-cancer) health risks from inhalation exposure
- Chronic health risks from dermal (skin) exposure
- Cancer risks
- Chemical safety concerns

The risk screening was based on the exposures expected in a model facility. The characteristics of this model facility were developed from several sources including PWB facilities, supplier data, and input from PWB manufacturers at project meetings. The model was not entirely representative of any one facility, and actual risk at a facility could vary substantially, depending on site-specific operating conditions and other factors.

Several assumptions are associated with this approach. These include assumptions that workers do not wear gloves, that all non-conveyorized lines are operated by manual hoist, and that the air concentration of chemicals is constant over time. These assumptions are applied consistently for all surface finishes evaluated. Significant uncertainties are associated with all risk assessments. In this analysis, uncertainties arise from the lack of toxicological data for some chemicals, the potential inaccuracy of the release and exposure models, and the lack of information about potential acute effects resulting from exposure to chemicals at peak concentration levels.

Inhalation Risks

During the surface finishing process, chemicals can be released to the air either by evaporation of the volatile chemicals or by the formation of aerosols as tank contents are stirred. The DfE study assumed inhalation exposure only for non-conveyorized presses. Workers on conveyorized process lines were expected to have a negligible rate of exposure by inhalation because the lines are typically enclosed and vented to the outside.

Workers using non-conveyorized systems can inhale chemicals that pose potential risks.

- The Nickel/Gold and Nickel/Palladium/Gold processes had the highest number of chemicals of concern.

The risk screening and characterization in the CTSA comprised a five-step process:

- The **source release assessment** identifies possible sources of environmental releases from surface finishing and, in some cases, discusses the nature and quantity of those releases.
- The **exposure assessment** quantitatively estimates occupational and general population exposures to surface finishing chemicals.
- The **hazard data assessment** presents human health hazard and aquatic toxicity data for surface finishing chemicals.
- The **risk characterization** combines the previous two steps to measure the situation-specific risk of the surface finishing chemicals.
- The **process safety assessment** summarizes chemical safety hazards from material safety data sheets (MSDSs) for surface finishing chemical products and discusses process safety issues.

A chemical is of concern when it is present at a concentration that toxicological research indicates may cause adverse effects in humans or aquatic organisms.

- Of the five non-conveyorized processes, only Immersion Tin contained no chemicals that presented a concern from inhalation.
- Most chemicals of concern are used either in cleaning or finish deposition steps.

Table 4.1 Chemicals of Concern for Inhalation Risk[a]

Chemical	Process Step	HASL	Nickel/Gold	Nickel/ Palladium/Gold	OSP
Alkyldiol [b]	[b]		✓	✓	
Ethylene glycol	Cleaner, microetch	✓			✓
Hydrochloric acid	Acid dip, catalyst, cleaner		✓	✓	
Hydrogen peroxide	Microetch		✓	✓	
Nickel sulfate	Electroless nickel		✓	✓	
Phosphoric acid	Cleaner		✓	✓	
Propionic acid	Electroless palladium			✓	

[a] Immersion tin and immersion silver did not contain any chemicals that presented a concern from inhalation exposure.
[b] Actual name is Confidential Business Information; the process step is withheld to protect the chemical's identity.

For lead, the relationship between exposure level and health effects is complex. As a result, the health risks of lead were assessed separately using several data sources, including facility-level monitoring data, and modeling results of the relationship between exposure rates and the concentration of lead in blood.

Dermal Risks

Dipping boards, adding bath replacement chemicals, or testing bath chemistry can expose workers to chemicals though the skin. Risks were calculated for both line operators and laboratory technicians. Although industry survey results indicate that most line operators wear gloves, this analysis measured the risk to workers who do not wear gloves to account for the fraction that do not. It is important to note that dermal risk is usually negligible when workers wear proper gloves and other protective equipment.

Most technologies pose a potential risk from dermal exposure when gloves are not worn.

- All technologies except Immersion Silver and conveyorized Immersion Tin presented a potential dermal risk to workers who do not wear gloves.
- Both line operators and laboratory technicians may be exposed to chemicals of concern.

- The **potential dermal risks for conveyorized processes were lower** than those for non-conveyorized processes. (Conveyorized processes were expected to result in dermal exposure only for maintenance tasks; non-conveyorized processes result in dermal exposure for both routine operation and maintenance.)
- For laboratory technicians, fewer chemicals were of concern for most technologies because laboratory technicians are expected to have lower exposure rates.
- Most chemicals of concern are used in cleaning or microetch steps.
- The risks associated with lead in HASL are uncertain. Monitoring data indicated that the level of lead in workers' blood was one-sixth to one-half of the lowest federal target/action levels. However, model results indicated that lead levels potentially could be considerably above target/action levels if workers do not wash their hands after handling lead.

Table 4.2 Chemicals of Concern for Dermal Risk[a]

Chemical	Process Step	HASL		Nickel/ Gold	Nickel/ Palladium/Gold	Immersion Tin	OSP	
		NC	C	NC	NC	NC	C	NC
Ammonia compound A[b]	[b]				✓			
Ammonium chloride	Immersion gold			✓				
Ammonium hydroxide	Immersion gold			✓	✓			
Copper ion	OSP						✓✓	✓✓
Copper salt C[b]	[b]							✓
Copper sulfate pentahydrate	Microetch	✓✓	✓✓	✓✓	✓✓		✓✓	✓✓
Hydrogen peroxide	Microetch			✓	✓			
Inorganic metallic salt B[b]	[b]			✓✓	✓✓			
Lead	Solder	X	X					
Nickel sulfate	Electroless nickel			✓✓	✓✓			
Urea compound C	[b]					✓		

[a] Immersion Silver and conveyorized Immersion Tin did not contain any chemicals that presented a concern from dermal exposure.
[b] Actual name is Confidential Business Information; the process step is withheld to protect the chemical's identity.
✓ Line operator risk results above concern levels
✓✓ Line operator and laboratory technician risk results above concern levels
X Risk indicators were not calculated for lead as with the other chemicals. Other information, however, indicates that incidental ingestion of lead from contact with hands could result in lead exposure at levels of concern.
NC: Non-conveyorized (vertical) process configuration.
C: Conveyorized (horizontal) process configuration.

Cancer Risks

A surface finish technology poses a potential cancer risk if chemicals in the formulations are carcinogenic (cancer-causing). However, the carcinogenic properties are not known for all chemicals. Therefore, chemicals are classified into carcinogen categories based on the strength of evidence that a chemical does cause cancer, as follows:

- The classification of *human carcinogen* indicates that there is sufficient evidence that a chemical causes cancer in humans.
- A *probable human carcinogen* has some evidence that it causes cancer in humans, but not sufficient evidence to classify it as a human carcinogen.
- A *possible human carcinogen* has sufficient evidence that the substance causes cancer in animals but inadequate or a lack of evidence in humans.
- Other possible classifications are that the chemical is not classifiable as to its carcinogenicity to humans, or that the chemical is probably not carcinogenic to humans.

The cancer risks of the surface finishes are either low or not quantifiable.

For known carcinogenic chemicals, it is assumed that any level of exposure can put a person at risk for cancer. The probability of developing cancer from that chemical can be determined from the use of slope factors. These quantitative measures were only available for the one carcinogenic chemical used in the study: **inorganic metallic salt A** in the **Nickel/Gold** process. For workers, this chemical has a maximum individual cancer risk over a lifetime of one iin five million at the typical concentrations in a PWB facility. Because this risk is less than one in a million, the cancer risk is considered to be of low concern.

Other chemicals may be carcinogenic:

- Lead is a possible human carcinogen used in the HASL process.
- Thiourea is a possible human carcinogen used in the Immersion Tin process.
- Urea compound B is a possible human carcinogen used in the Nickel/Gold and Nickel/Palladium Gold processes.
- Strong sulfuric acid mist is known to be a human carcinogen. Sulfuric acid is used in all of the evaluated surface finishes, but in a diluted form; it is not expected to be released to the air as a strong acid mist.

The cancer risks associated with these chemicals could not be determined because the slope factors of the chemicals have not been developed.

Summary of Worker Health Risks

Several of the alternative surface finishes evaluated may offer an improvement in potential worker health risks over non-conveyorized HASL. Each conveyorized process (Immersion Silver, Immersion Tin, OSP, and HASL), as well as non-conveyorized Immersion Tin, was operated without exposing workers to chemicals of concern through inhalation. Furthermore, Immersion Silver, Immersion Tin, and OSP had fewer chemicals of concern for dermal exposure. However, the results highlight the importance of good workplace ventilation and of wearing gloves; all of the technologies except Immersion Silver and conveyorized Immersion Tin contain at least some chemicals that are of concern when workers regularly handle them with bare hands.

Several uncertainties remain about the relative risks of these technologies. The cancer risks of three possible carcinogens — lead, thiourea, and urea compound B — are not known. With regard to chronic health effects, several chemicals have only limited or no toxicological information. The uncertainty associated with lead levels in the blood of workers indicates that despite the considerable attention given to reducing lead in the workplace, little is known about the quantitative risks that workers operating the HASL process face.

Chemical Safety

All of the surface finish technologies in this study use formulations that may harm workers when mishandled.

In addition to chronic health and carcinogenic risks, surface finish formulations may pose an immediate safety hazard to workers. For each technology, the chemicals were evaluated to determine if any were flammable, explosive, a fire hazard, corrosive, an oxidizer, capable of a sudden release of pressure upon opening, unstable, combustible, or reactive.

Table 4.3 presents the safety hazards associated with each system as indicated by the Material Safety Data Sheets (MSDSs). A check mark indicates that at least one chemical used for that technology presents a particular type of hazard. There is a range in the types and number of hazards associated with the different technologies. Immersion Tin presented concern only for explosiveness and corrosiveness, but HASL presented a concern for seven of the nine listed hazard categories. For each of the technologies, it is important to follow the handling instructions provided by the supplier.

Table 4.3 Chemical Safety Information

Hazard	HASL	Nickel/ Gold	Nickel/ Palladium/Gold	Immersion Silver	Immersion Tin	OSP
Flammable	✓					✓
Explosive	✓			✓	✓	
Fire Hazard	✓			✓		✓
Corrosive	✓	✓	✓	✓	✓	✓
Oxidizer	✓	✓	✓	✓		✓
Sudden Release of Pressure	✓	✓	✓			✓
Unstable	✓			✓		
Combustible						
Reactive						

Question 5

How may surface finishes affect people and the environment outside the facility?

The PWB surface finish application process produces air and water wastes that could impact a facility's surroundings. Air emissions result from vapors that are generated from chemicals used in manufacturing, such as baths and drying ovens. Water releases occur when rinse water is sent to the sewer system or into the environment, after meeting treatment requirements.

There are two areas of potential concern for these releases. The general public may be at risk to the vapors emitted to the air that are carcinogenic or cause other long-term health problems. Aquatic organisms may be adversely affected if their water bodies are contaminated with toxic chemicals. The risk characterization for the surface finish technologies modeled the potential risks to these two groups.

Public Health Risks

The public may be exposed to the vapors of PWB chemicals, which are released through vents or escape through doors and windows.

Risks to nearby residents are minimal for all technologies.

Public health risk was estimated for inhalation exposure from each type of surface finish for people living near a facility (defined as within 100 meters of a facility). For both cancer and non-cancer effects, the impacts on public health are expected to be small. One chemical, inorganic metallic salt A in the Nickel/Gold process, is a known human carcinogen. However, the estimated lifetime risk of getting cancer from this chemical at the expected exposure rate for a resident is $2x10^{-11}$ (one in 50 billion). The cancer risks associated with those chemicals classified as "probable" or "possible" carcinogens, including lead, thiourea, and strong sulfuric acid mists, were not known.

Non-cancer inhalation effects were expected to be low as well. Based on available information, it appears that the chemicals used in the surface finishes would be found in the air outside the facility in concentrations too low to cause significant concern for health effects. It should be noted that toxicity information was inadequate or absent for some chemicals, and that the public potentially could be at risk from surface finish processes through other pathways, including solid waste releases or contaminated drinking water.

Ecological Risks

An ecological indicator value greater than one indicates that the chemical is present in wastewater at a concentration that may harm aquatic organisms.

Wastewater from most surface finish processes is capable of harming aquatic organisms.The discharge of wastewater 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 meet the permitting regulations of their federal, state, or local authority. State and local permits may require even stricter limits than are required by the federal government.

Most metals used are regulated and must not exceed regulated levels upon release. Although metals are present in wastestreams in concentrations above levels of concern for some surface finishes, most are removed before discharge, in accordance with regulations.

Ecological risks were estimated by calculating the concentration of each chemical in surface finish process wastewater, then dividing that by the concentration of concern (CC) – the concentration at which a chemical is expected to present risks to organisms in aquatic ecosystems. This ratio is called an aquatic risk indicator. A value greater than one indicates that the chemical is present in wastewater at a concentration that may harm aquatic organisms. The calculations assumed that the wastewater is treated by a publicly owned treatment works (POTW), which reduces the concentration of many chemicals by approximately 90%.

As indicated in Table 5.1, each technology except Nickel/Gold and Nickel/Palladium/Gold had chemicals with an aquatic risk indicator greater than one. Therefore, if the wastewater from the other technologies were released to a body of water after being processed at a treatment facility, it could adversely affect organisms in the water. HASL contained the most chemicals with an indicator greater than one. There were four chemicals in the HASL non-conveyorized process and five in the conveyorized process. The most significant chemical, however, is alkylaryl imidazole used in OSP. The concentration of this chemical can be 3.6 to 33 times greater than the threshold at which effects appear. This indicates that facilities should make sure the alkylaryl imidazole in the wastewater from the OSP process is treated prior to disposal.

Table 5.1 Aquatic Risks of Surface Finish Chemicals

Process	HASL	Nickel/ Gold	Nickel/ Palladium/ Gold	Immersion Silver	Immersion Tin	OSP
Number of Non-Metal Chemicals with Indicator >1[a]	3-4	0	0	1	0-1	1
Chemical with Largest Aquatic Risk Indicator	Potassium peroxy-monosulfate	None > 1	None > 1	Hydrogen peroxide	Potassium peroxy-monosulfate	Alkylaryl imidazole
Aquatic Risk Indicator	8.2 (NC) 6.1 (C)	—	—	1.3	3.6 (NC)	6.6-33 (NC) 3.6-18 (C)

[a] This table only contains non-metal pollutants. It is assumed that metals are removed from wastewater at the facility during pretreatment in order to comply with discharge permit requirements.

NC: Non-conveyorized (vertical) process configuration.

C: Conveyorized (horizontal) process configuration.

Question 6

What kind of performance can I expect from alternative surface finishes?

Surface finishes were applied to test boards at volunteer facilities.

The performance of the surface finishes was evaluated by processing standardized test panels at 13 volunteer PWB facilities, where the finishes were already in use. Each volunteer facility ran the boards through their surface finish line during their normal production operation. The information collected through the demonstrations was intended to provide a "snapshot" of the way the technology was performing at a particular facility at that particular time.

This study was intended to provide a "snapshot" of the performance of different surface finishes. It was not a substitute for thorough facility-specific testing to determine what works best for your operation.

Each supplier was asked to submit the names of up to two facilities at which they would like the demonstrations of their technology to be conducted. This selection process encouraged the suppliers to nominate the facilities where their technology was performing at its best. This, in turn, provided for more consistent comparisons across technologies.

After each PWB facility completed the surface finish application, the boards were assembled using either a halide-free low-residue flux or a halide-containing water soluble flux. The electrical performance of the assembled boards (164 boards in total) then was tested before and after exposure to accelerated aging, thermal shock, and mechanical shock conditions.

The test board was designed to represent a variety of circuits.

The test board used was based on a design for the Circuit Card Assembly and Materials Task Force (CCAMTF), a joint industry and military initiative. The test board is 1994 technology and does not incorporate today's state-of-the-art circuitry, as it would not be possible to have a test vehicle keep pace with today's rapid changes in circuit technology. The test printed wiring assembly (PWA) was divided into six sections, each containing one of the following types of electronic circuits:

The functional test boards included a variety of extreme circuits to maximize the applicability of the test results.

- High current low voltage (HCLV)
- High voltage low current (HVLC)
- High speed digital (HSD)
- High frequency (HF)
- Other networks (ON)
- Stranded wire (SW)

The components in the HCLV, HVLC, HSD, and HF circuits represented both plated through-hole (PTH) components, which were wave soldered, and surface mount technology (SMT) components, which were soldered through a reflow oven. The other networks were used for current leakage measurements: 10-mil pads, a socket for a PGA, and a gull wing. The two stranded wires were hand soldered. The test board provides 23 separate electrical responses as shown in Table 6.1.

Table 6.1 Electrical Responses for the Test PWA and Acceptance Criteria

Response	Circuitry	Acceptance Criteria
	High Current Low Voltage	
1	HCLV PTH	Δ Voltage from Pre-test < 0.50V
2	HCLV SMT	Δ Voltage from Pre-test < 0.50V
	High Voltage Low Current	
3	HVLC PTH	4μA < X < 6μA
4	HVLC SMT	4μA < X < 6μA
	High Speed Digital	
5	HSD PTH Propagation Delay	< 20% increase from Pre-test
6	HSD SMT Propagation Delay	< 20% increase from Pre-test
	High Frequency Low Pass Filter	
7	HF PTH 50 MHz	±5dB of Pre-test
8	HF PTH f(–3dB)	±50MHz of Pre-test
9	HF PTH f(–40dB)	±50MHz of Pre-test
10	HF SMT 50 MHz	±5dB of Pre-test
11	HF SMT f(–3dB)	±50MHz of Pre-test
12	HF SMT f(–40dB)	±50MHz of Pre-test
	High Frequency Transmission Line Coupler	
13	HF TLC 50MHz Forward Response	±5dB of Pre-test
14	HF TLC 500MHz Forward Response	±5dB of Pre-test
15	HF TLC 1GHz Forward Response	±5dB of Pre-test
16	HF TLC Reverse Null Frequency	±50MHz of Pre-test
17	HF TLC Reverse Null Response	< 10dB increase over Pre-test
	Other Networks—Leakage	
18	10 mil Pads	Resistance > 7.7 $\log_{10}$ ohms
19	PGA A	Resistance > 7.7 $\log_{10}$ ohms
20	PGA B	Resistance > 7.7 $\log_{10}$ ohms
21	Gull Wing	Resistance > 7.7 $\log_{10}$ ohms
	Stranded Wire	
22	Stranded Wire 1	Δ Voltage from Pre-test < 0.356V
23	Stranded Wire 2	Δ Voltage from Pre-test < 0.356V

Boards were exposed to stress conditions.

Each of the 164 PWAs was exposed to the following environmental, thermal, and mechanical shock test sequence:

1. Exposure to three weeks of 85°C and 85% relative humidity
2. 200 cycles of thermal shock with the PWAs rotated between chambers at –50°C and 125°C, with 30 minute dwells at each temperature
3. Mechanical shock, where the PWA was mounted in a rectangular fixture and dropped 25 times on a concrete surface from a height of 1 meter

Over 15,000 test measurements were recorded.

The PWAs were functionally tested at four test times: Pre-test, Post 85/85, Post Thermal Shock, and Post Mechanical Shock. At each of the four test times, 164×23 = 3772 electrical test measurements were recorded. An overall summary of success rates is shown for each major circuit group in Table 6.2. (These values are based on 3,608 measurements at each test time. Because the 164 HF TLC RNF measurements gave a constant response of 50 MHz throughout, there was no variability to analyze.)

Table 6.2 Overall Success Rates, by Circuit Type and Test Time

Circuitry	85/85	Thermal Shock	Mechanical Shock
HCLV	100.0%	100.0%	48.2% (7.1% SMT)
HVLC	99.7%	99.7%	50.0% (0.0% SMT)
HSD	99.7%	98.8%	99.1% (99.3% SMT)
HF LPF	98.7%	89.4%	82.6% (74.8% SMT)
HF TLC	99.8%	99.5%	99.4%
Other Networks	99.8%	100.0%	100.0%
Stranded Wire	100.0%	99.7%	98.5%
Total % Success Rate	**99.5%**	**96.9%**	**85.4%**
Total anomalies per test time	**17**	**113**	**527**

It should be noted that the acceptance criteria are not absolutes, but rather guidelines. This distinction is notable when values fall just outside the acceptance criterion and may be considered "not of practical significance."

Table 6.3 summarizes how problem areas developed during exposure to the three test conditions.

Table 6.3 Frequency of Anomalies by Individual Circuit over Test Times

Circuitry		Post 85/85	Post TS	Post MS	Comments
HCLV					
1	**HCLV PTH**	0	0	12	Some need further Failure Analysis
2	**HCLV SMT**	0	0	158	SMT components came off board during MS
HVLC					
3	**HVLC PTH**	0	0	0	Excellent performance throughout
4	**HVLC SMT**	1	1	164	SMT components came off board during MS
HSD					
5	**HSD PTH**	0	2	2	Component problem
6	**HSD SMT**	1	2	1	Component problem
HF LPF					
7	**HF PTH 50 MHz**	4	15	15	Failure Analysis of open PTH needed
8	**HF PTH f(-3dB)**	4	15	18	Failure Analysis of open PTH needed
9	**HF PTH f(-40dB)**	4	13	14	Failure Analysis of open PTH needed
10	**HF SMT 50 MHz**	0	18	30	Failure Analysis of open PTH needed
11	**HF SMT f(-3dB)**	0	16	29	Failure Analysis of open PTH needed
12	**HF SMT f(-40dB)**	1	27	65	Failure Analysis of open PTH needed
HF TLC					
13	**HF TLC 50MHz**	0	0	7	Minor anomalies
14	**HF TLC 500MHz**	0	0	1	Minor anomalies
15	**HF TLC 1GHz**	0	1	1	Minor anomalies
16	**HF TLC RNF**	0	0	0	Constant response of 50MHz throughout
17	**HF TLC RNR**	1	2	5	Minor anomalies
Leakage					
18	**10-Mil Pads**	0	0	0	Excellent performance throughout
19	**PGA A**	0	0	0	Excellent performance throughout
20	**PGA B**	0	0	0	Excellent performance throughout
21	**Gull Wing**	1	0	0	Excellent performance throughout
Stranded Wire					
22	**SW 1**	0	0	1	Excellent performance throughout
23	**SW 2**	0	1	4	Minor anomalies

Statistical analyses of results were conducted.

General linear models (GLMs) were used to analyze the test data for each of the 23 electrical circuits in Table 6.1 at each test time. The GLM analyses are extremely useful in identifying which experimental factors or combinations of factors explain a statistically significant portion of the observed variation in the test results and in quantifying their contribution. Another statistical approach, with an analysis of variance (ANOVA), was used to determine which groups of site/flux *means* were significantly different from one another for a given electrical response from the test PWA.

In the CTSA document, boxplots are used for convenient displays of multiple comparison results.

Overall, the alternative surface finishes performed as well as, if not better than, HASL.

The analysis of the tested boards showed no failures that could be definatively related to any particular surface finish. There were failures , however, which are described below for each type of circuitry.

HVLC PTH, HSD, HF TLC, Leakage Circuits, and Stranded Wire

For most circuits, results of the GLM analyses showed no practical significance relative to the acceptance criteria, which indicates that surface finish, flux, and site did not influence the test measurements. These circuits include High voltage low current (HVLC) plated through holes (PTH); High speed digital (HSD); High frequency (HF) transmission line coupler (TLC); Leakage circuits (10-mil Pads, PGA-A, PGA-B, Gull Wing); and Stranded Wire.

While no surface finish-related effects were seen, there were some anomalies, as summarized in Table 6.3. The sources of three types of anomalies of note are explained below; none of these are surface finish-specific.

- Some anomalies were seen at various test times for the **HSD circuits**. However, the testing technician indicated that these anomalies occurred because the HSD device itself failed (and that they were unrelated to the surface finish).
- In the **HF TLC** and **Stranded Wire** circuits, there were several minor anomalies. They were very close to the acceptance criteria guidelines and are not considered of practical concern.
- The **leakage** circuits showed excellent performance across tests and across surface finishes. However, for all leakage circuits, the GLM analyses showed an effect due to flux. These differences from the base case essentially disappeared after exposure to the 85/85 test environment. This result was not unusual and may be due to a *cleansing effect* from the 85/85 test environment that removes residues resulting from board fabrication, assembly, and handling. This phenomenon was observed for all leakage circuits.

HCLV SMT and HVLC SMT

Over 300 anomalies were introduced on HCLV SMT and HVLC SMT circuits during mechanical shock testing. These anomalies were attributed to separation of SMT components due to the severity of the mechanical shock testing (i.e., 25 drops on concrete from a height of 1 meter). This affected every board, and failures were equally distributed across all surface finishes, including the HASL baseline. When assessing the HCLV SMT and HVLC SMT results, product and process designers should consider the severity of the mechanical shock test.

HF LPF

The GLM analyses indicated that surface finish, flux, and site did not influence the HF LPF measurements at any of the test times. However, the test measurements contained many extreme outlying observations at post thermal shock and post mechanical shock, which greatly increases the sample variance and in turn hinders the interpretation of the GLM results. The HF LPF anomalies are summarized by surface finish in Table 6.4 for each of the six HF LPF circuits.

Table 6.4 Observed Number of HF LPF Anomalies (Compared to the Expected Number)

Process	HASL	Ni/Au	Ni/PD/Au	Imm Silver	Imm Tin	OSP	TOTALS
No. of PWAs	32	28	12	20	36	36	164
HF LPF PTH							
50 MHz	1 (2.9)	2 (2.6)	0 (1.1)	6 (1.8)	4 (3.3)	2 (3.3)	15
f(-3dB)	2 (4.1)	3 (3.6)	0 (1.5)	6 (2.6)	5 (4.6)	2 (4.6)	18
f(-40dB)	1 (2.9)	2 (2.6)	0 (1.1)	7 (1.8)	3 (3.3)	1 (3.3)	14
HF LPF SMT							
50 MHz	6 (5.9)	0 (5.1)	0 (2.2)	7 (3.7)	11 (6.6)	6 (6.6)	30
f(-3dB)	7 (5.9)	0 (5.1)	0 (2.2)	6 (3.7)	11 (6.6)	5 (6.6)	29
f(-40dB)	15 (13.1)	1 (11.4)	1 (4.9)	11 (8.2)	17 (14.7)	20 (14.7)	65

The test technician indicated that most of the HF LPF anomalies were due to an open PTH, which affects both PTH and SMT. Although an open PTH is a fabrication issue, there does appear to be a relationship with surface finish. Under the assumption that the anomalies occur independently of surface finish, the expected number of anomalies can be calculated for each cell. A chi-square statistic was calculated on the differences of the observed and expected number in each cell.

While there were no significant differences in the number of anomalies among the surface finishes for the HF LPF PTH 50 MHz and HF LPF PTH f(-3dB) circuits, such was not the case for the other HF LPF circuits. For these circuits, the statistical analysis indicated that the anomalies were not independent of surface finish. The expected values for anomalies appear in parenthesis in each cell in Table 6.4. These comparisons showed:

- HASL anomalies were close to the expected values throughout.
- Nickel/Gold and Nickel/Palladium/Gold had far fewer anomalies than expected.
- Immersion Silver had many more anomalies than expected for all circuits.
- Immersion Tin anomalies were close to expected for PTH circuits, but were higher than expected for SMT circuits.
- OSP anomalies were close to expected, except for the f(-40dB) circuit, where they had more anomalies than expected.

The number of open PTH anomalies may be related to the inherent strength of the metals. Tin and silver are relatively weak; OSP has no metal, and nickel makes the PTH stronger. To determine the relevancy of metal strength to the open PTH anomalies, the HF LPF circuits would need to be subjected to failure analysis to check for copper plating thickness and PTH voids in the vias, as both of these may be problems in small vias. In addition, the chemical removal of copper from the via may be much greater in Immersion Tin and Immersion Silver, depending on how they were processed.

Nickel/Gold and Nickel/Palladium/Gold had fewer HF LPF anomalies than expected, and Immersion Silver had more than expected.

In general, problems related to open PTHs result from a combination of board fabrication materials and processes and board design (e.g., the small diameter vias in the HF LPF circuit). Product designers should be aware of these phenomena when considering a change to a new surface finishes.

HCLV PTH

Although none of the HCLV PTH voltage measurements exceeded the acceptance criterion of $\Delta V <$ 0.50V after exposure to 85/85 or Thermal Shock, there were 12 HCLV PTH anomalies following Mechanical Shock. Several of the differences were well above the acceptance criteria. A significant difference in means was found for this circuit at Post Mechanical Shock, and is attributed mostly to Immersion Silver at one site processed with water soluble flux. It should be noted, however, that the other two Immersion Silver sites showed no anomalies. This may indicate a site-specific problem and not a surface finish problem. While additional failure analysis would be needed to draw further conclusions, in this level of testing, Immersion Silver had more anomalies than expected (5 of 12), and Nickel/Gold and Nickel/Palladium/Gold had fewer anomalies than expected (0 of 12).

The Failure Analysis showed no link between 85/85 failures and any of the surface finishes.

Following the analysis of the test boards, ion chromatography was used as a tool to analyze boards that failed 85°C/85%RH exposure. Contamination Studies Laboratories, Inc. (CSL) in Kokomo, Indiana, conducted this failure analysis. The purpose of the analysis was to determine if any links exist between board contamination from fabrication and assembly process residues and the electrical anomalies.

The testing analyzed the residue species per square inch of extracted surface ($\mu g/in^2$); specifically, bromide, weak organic acids (WOAs), and chloride were analyzed. Tests were conducted on a set of boards that failed after 85/85 testing, and a control group of boards that were not subjected to the 85/85 environment.

Based on CSL's guidelines, the observed bromide and WOA levels on all assemblies and the chloride levels on the group of test boards were typical, and as such do not pose a threat for electrochemical failures. The two untested (control) boards with the HASL finish exhibited levels significantly above CSL's recommended limits, and are therefore at risk for electrochemical failures. Ineffective cleaning is the likely culprit. The one tested HASL board with the reported anomaly exhibited a level only slightly above CSL's recommended limit.

Question 7

Will alternative surface finishes reduce my costs?

The cost of each surface finish technology was modelled to determine the relative expenses required for each, and to identify the most costly components within each technology. The cost analysis included capital, material, utility, licensing/permit, production, and maintenance costs. Table 7.1 presents a breakdown of the costs considered in the analysis, and Figure 7.1 displays the costs for each technology, with non-conveyorized HASL (the baseline) highlighted for comparison. The costs for each technology were calculated for processing 260,000 surface square feet (ssf) of board — the average yearly production at facilities using the HASL process. Some potentially significant costs were not included in the analysis, such as costs associated with on-site wastewater treatment and sludge disposal, and costs of any changes elsewhere in the process required prior to implementing the surface finish.

The cost analysis estimated the costs associated with each surface finish technology over 260,000 surface square feet (ssf) – the typical throughput at facilities using the baseline HASL process.

Table 7.1 Costs Considered in Analysis

Cost Category	Component
Material cost	Process chemical(s)
Production	Transportation of material
	Labor for normal production
Maintenance cost	Tank cleanup
	Bath setup
	Sampling and testing
	Filter replacement
Capital	Primary equipment and Installation
	Facility (floor space)
Utility cost	Water
	Electricity
	Natural gas
Licensing/permit cost	Wastewater discharge

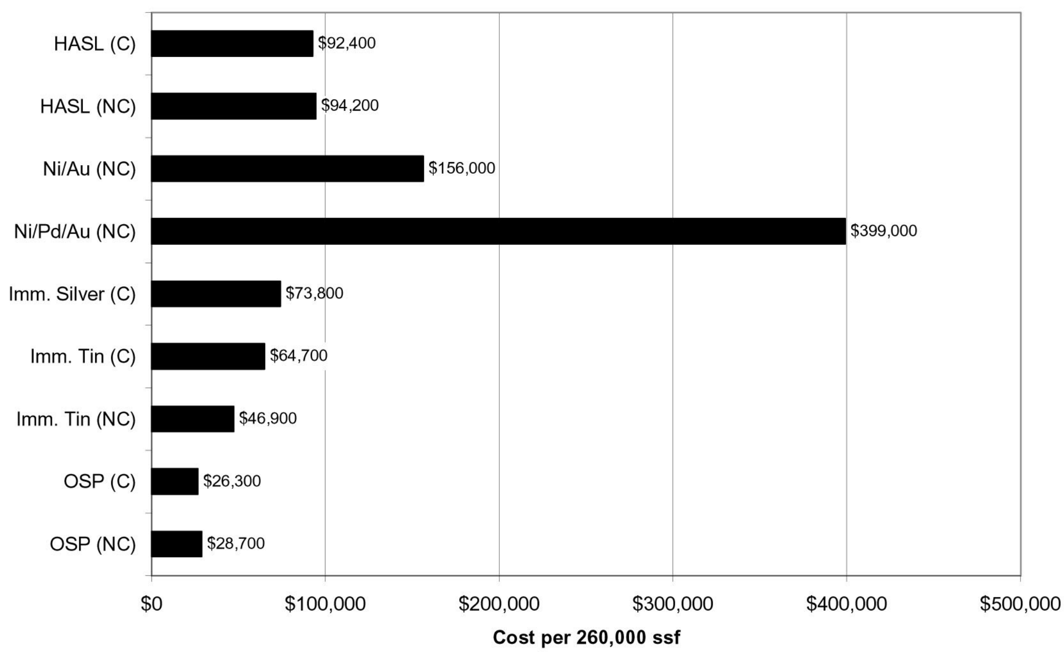
Many alternative surface finishes cost less to use than HASL.

Conveyorized OSP was the least expensive surface finish per 260,000 surface square feet (ssf), and Nickel/ Palladium/ Gold was the most expensive.

- Most processes were less expensive than HASL, because the material costs were lower.

- The Nickel/Gold and Nickel/Palladium/Gold processes were more expensive, because of their precious metal content.
- **Conveyorized processes** generally cost less per board than non-conveyorized processes of the same technology, because of higher throughput rates.

Figure 7.1 Surface Finish Costs



Material costs are the most expensive component of each technology.

Table 7.2 shows the different cost components for each technology.

- **Material (chemical) costs** are the main cost drivers.
- **Throughput rate** is an important factor for labor and capital costs, because these costs are lower per board if more boards are processed in a given time.
- Because capital costs are a relatively minor cost compared to material costs (which are recurring), the replacement costs associated with switching to an alternative technology may be easy to overcome.

Table 7.2 Cost Categories for Surface Finishes per 260,000 ssf

Process	HASL		Ni/Au	Ni/Pd/Au	OSP		Immersion Silver	Immersion Tin	
	C	NC	NC	NC	C	NC	C	C	NC
Material	$75,200	$74,800	$109,000	$321,000	$18,800	$18,500	$52,700	$28,900	$29,000
Production	$1,920	$4,110	$19,800	$26,200	$1,440	$3,330	$5,430	$8,940	$6,980
Maintenance	$1,880	$2,950	$11,000	$20,900	$1,960	$3,340	$2,500	$4,280	$3,770
Capital	$11,500	$9,790	$10,200	$21,500	$3,140	$1,950	$11,400	$19,100	$3,840
Utility	$1,062	$1,460	$3,540	$6,110	$541	$821	$1,180	$2,170	$1,686
Wastewater	$851	$1,100	$2,050	$3,530	$463	$704	$529	$1,220	$1,620
Total	$92,400	$94,200	$156,000	$399,000	$26,300	$28,700	$73,800	$64,700	$46,900

NC: Non-conveyorized (vertical) process configuration.
C: Conveyorized (horizontal) process configuration.

Question 8

Do alternative surface finishes use less water, metal, and energy?

Resource consumption for each surface finish technology was determined by calculating the water, metal, and energy use per 260,000 ssf.

Facilities using water conservation techniques can reduce water consumption. Examples include counter-current or cascade rinse systems, ion exchange or reverse osmosis devices, or reuse of water elsewhere in the plant.

Water Consumption

Water is consumed during rinse stages in each surface finish technology. The rinses remove contaminants from previous steps in the process and provide a clean surface on which to begin a subsequent step. In PWB manufacturing, water use can be a significant concern – incoming water may require purification, thereby necessitating purification equipment with a capacity large enough to match the needs of the facility. In addition, process wastewater usually requires pretreatment before being released.

Several alternative surface finishes consumed less water than HASL.

Table 8.1 presents the water consumption rates for each of the surface finish technologies. The consumption rates were based on estimated flow rates of 0.258 gal/ssf for non-conveyorized processes, 0.176 gal/ssf for conveyorized processes, and 0.465 gal/ssf for high-pressure water rinses on both automation types. These flow rates were derived from industry surveys. The number of rinses indicated in the table was based on supplier recommendations; facility practices may vary and may have more rinse steps or higher water flow rates.

- The **Immersion Silver**, **OSP**, and **Conveyorized Immersion Tin** processes consumed less water than the baseline. The primary driver was the lower number of rinses required. Those that consumed more water — non-conveyorized Immersion Tin, Nickel/Gold, and Nickel/Palladium/Gold, are more complex processes and require more rinse steps than HASL.
- **Conveyorized** processes consumed less water than the corresponding non-conveyorized processes. With the higher throughput of conveyorized processes, less water is used per surface square foot of PWB at each rinse station.

Table 8.1 Water Consumption by Surface Finish Technologies

Process	HASL		Ni/Au	Ni/Pd/Au	Immersion Silver	Immersion Tin		OSP	
	C	NC	NC	NC	C	C	NC	C	NC
Number of Rinses	3 (1)	3 (1)	8	14	3	5	7	3	3
Rinse Water Consumed (gal/260,000 ssf)	258,000	**322,000**	537,000	939,000	137,000	229,000	469,000	137,000	201,000

[a] Number in parentheses indicates the number of rinse stages that are high-pressure washes.

NC: Non-conveyorized (vertical) process configuration.

C: Conveyorized (horizontal) process configuration.

Metal Consumption

Each surface finish technology, aside from OSP, uses metal. These metals are crucial to the electrical and protective properties that are needed in a surface finish. However, metals also are costly and can complicate waste management processes. By minimizing the use of metal, regardless of the toxicity and cost, the economic and environmental impacts of surface finish application can be reduced.

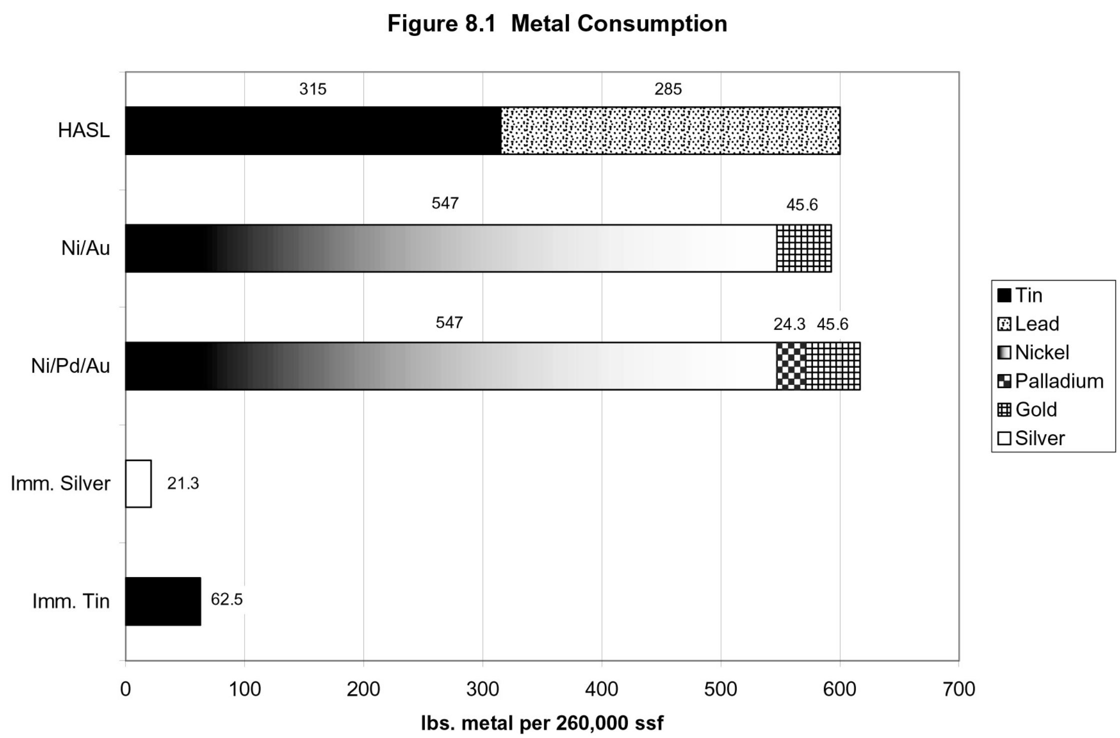
Several alternative surface finishes consume less metal per surface square foot than the baseline.

The amount of metal consumed varied considerably among the technologies. As shown in Figure 8.1, Nickel/Palladium/Gold consumed a combined 617 pounds of metal per 260,000 ssf, and HASL consumed 600 pounds. In contrast, Immersion Silver and Immersion Tin consumed only 21 and 63 pounds of metal, respectively, per 260,000 ssf. Because both conveyorized and non-conveyorized versions of a technology produce the same finish, there is no difference in metal consumption between the two.

It should be noted that these amounts do not include metal lost from dragout, nor do they account for the environmental impacts associated with mining these metals in the first place. For example, the impacts associated with mining a precious metal like gold are several times larger than those resulting from tin or lead mining.

The metal consumption calculations only include metal actually applied to the PWB. They do not include metal lost during the process due to dragout, and do not consider the fact that impacts associated with mining different metals vary.

Figure 8.1 Metal Consumption



Energy Consumption

Energy consumption per hour differs from energy consumption per unit area because the processes operate at different speeds.

Energy is used in the surface finish process to heat baths, operate pumps, and propel automated conveyorized or immersion equipment. For heating applications, natural gas is often used; for other applications, electricity is required. In each case, the demand for energy can be an expensive burden on a PWB facility.

Most processes consume more energy per ssf than the baseline.

The difference in energy consumption among the different technologies was driven by several factors. These include inherent differences in the processes as well as differences in the throughput rate and number of steps (and requisite heaters).

With the exception of the two OSP technologies and conveyorized HASL, each alternative consumed more energy than non-conveyorized HASL. In particular, the Nickel/Gold, conveyorized Immersion Tin, and Nickel/Palladium/Gold used more than twice the energy of the baseline. It should be noted that the consumption rate per square foot is different from the hourly consumption rate. HASL had the highest per-hour consumption rate because the process uses a drying oven and solder pot, yet had one of the lowest per square foot rates because of the high throughput rate. In contrast, Nickel/Gold had the lowest per hour energy consumption rate, but the low throughput rate resulted in a high energy rate per square foot. Figure 8.2 shows the results for each technology.

Figure 8.2 Energy Consumption

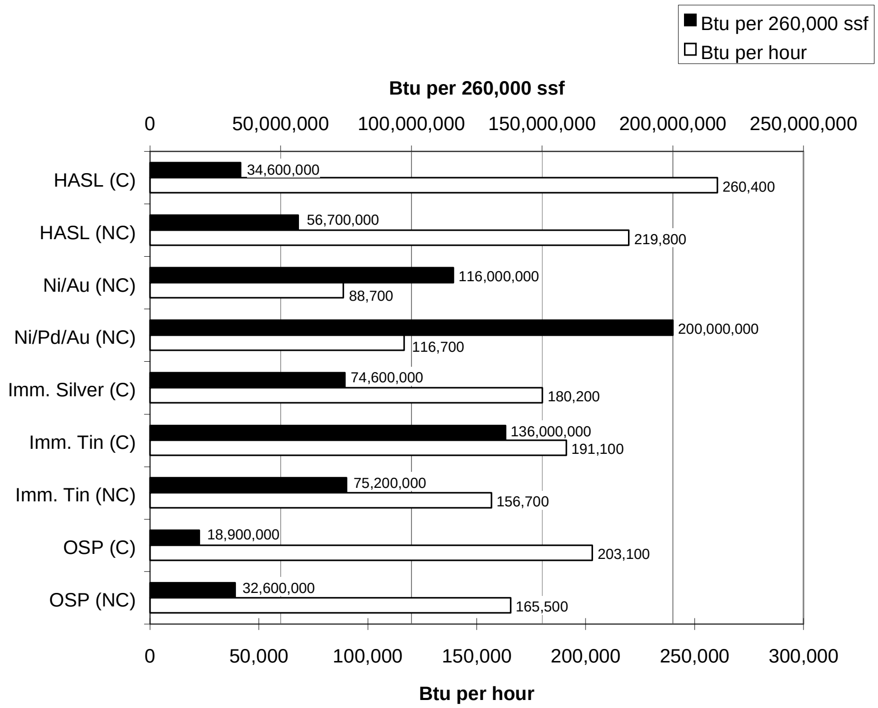


Table 8.2 presents the energy consumption rate for each type of equipment used for the surface finish technologies. The largest individual energy consuming device is the gas drying oven, which consumes 90 cu.ft. of natural gas per hour (27 kW). Every technology except Nickel/Gold and Nickel/Palladium/Gold used this device. In those two technologies, the majority of the energy consumption resulted from the use of immersion bath heaters in every tank.

Table 8.2 Energy Consumption by Surface Finish Equipment

Function of Equipment	Type of Equipment	Process	Energy Consumption (cu.ft./hr of Natural Gas or kW of Electricity)
Panel Drying	Gas Drying Oven	HASL Immersion Silver Immersion Tin OSP	90 cu.ft./hr[a]
Solder Heater	Solder Pot	HASL	20 kW
Conveyorized Panel Automation	Conveyor System	Conveyorized: HASL Immersion Silver Immersion Tin OSP	14.1 kW
Bath Heater	Immersion Heater	All	4.1 kW
Air Knife/ Sparging	Air Pump	HASL Nickel/Gold Nickel/Palladium/Gold OSP	3.8 kW
Panel Agitation	Panel Agitation Motor	Non-conveyorized: HASL Nickel/Gold Nickel/Palladium/Gold Immersion Tin OSP	3.1 kW
Fluid Circulation	Fluid Pump	All	0.9 kW

[a] Equivalent to 27 kW

Question 9

How can I make alternative surface finishes work for my facility?

Nearly all of the alternative surface technologies studied in the DfE analysis are used in commercial production. Therefore, other PWB manufacturers have been through the process of implementing these technologies and have learned how to make them work. As with any process change, facilities need to decide upon a specific technology, debug the process, implement any necessary changes to upstream or downstream processes, and train workers. The more a PWB manufacturer can learn about these considerations from others in advance of the installation, the smoother the implementation will be.

Another document produced by the DfE PWB Project, *Implementing Cleaner Printed Wiring Board Technologies: Surface Finishes* (EPA document 744-R-00-002), describes the experiences of PWB manufacturers, assemblers, and suppliers who have worked with these alternative surface finishes in production. The booklet provides information on these users' reasons for selecting each technology, difficulties encountered during installation and debugging, observed comparison to HASL, as well as general advice for others considering a new technology.

Although experiences differed among facilities, several recommendations emerged consistently for PWB manufacturers are summarized below.

Evaluate your facility's needs.

PWB manufacturers have added alternative surface finish lines for a number of reasons:

- To satisfy the request of a large customer
- To expand into the manufacture of other types of boards, or to finish boards that previously were finished at other facilities
- To produce a flatter finish
- To move toward an overall lead-free facility
- To reduce maintenance and equipment costs.

Each of these reasons comes with individual sets of conditions and motivations; focus on the specific motivations at your facility to ensure that the alternative surface finish you select is a good match for your needs.

Understand the surface finish technologies.

Every surface finish has limitations. Some are not wire bondable, and others may have a short shelf life, or an incompatibility with certain soldermasks. Also, the choice of surface finish can affect other steps in the PWB manufacturing process and in board assembly. Learn the details of the different finishes so that the one you select is a good match for your facility's technical needs. An important step in your evaluation is to arrange with a supplier or another PWB manufacturer to have sample boards finished with one or more of the candidate finishes.

Communicate with your customers.

Tell customers about your plans to add a new technology, so they understand the differences in the boards you will deliver, and so you can discuss which of their products might benefit from the new finish.

Work closely with the supplier.

Suppliers of the surface finish technology know the details of their product and the conditions under which it works best. When evaluating different candidate finishes, ask plenty of questions about each finish with respect to the type of boards it can run, process requirements, worker health issues, and waste disposal and permitting considerations.

After a specific finish has been selected, the supplier can provide you with guidance on the equipment you will need, any changes that you will have to make in upstream or downstream processes, and corrections to make during debugging.

Use quality equipment.

Several facilities and suppliers that have implemented an alternative technology have found that a considerable number of problems could be traced back to poor equipment. In one case an old film developer retrofitted as a bath caused contamination of the chemicals. Poor equipment also can lead to excessive drag-out, resulting in considerable raw material and waste disposal costs. Most of the alternative technologies have a tighter process window than HASL, so it is important to have equipment that is calibrated and that functions smoothly.

Achieve a total commitment from the company for the new process.

Everyone, especially management and line operators, must help in ensuring that the implementation process is successful. Line operators must learn how the process differs from the previous technology and how to address potential problems. Management must provide adequate resources for the installation, start-up, and debugging steps.

Question 10

Where can I find more information about pollution prevention in the PWB industry?

The DfE Printed Wiring Board Project has developed several materials specifically for the PWB industry. Ranging from technical reports to case studies, these sources provide information on several topics affecting the PWB manufacturing process including emerging technologies, pollution prevention opportunities, regulations, and Environmental Management Systems (EMSs). The Printed Wiring Board Project also has performed a detailed analysis on Making Holes Conductive (MHC) technologies. Several other documents provide industry-wide information and case studies of pollution prevention opportunities.

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
1200 Pennsylvania Ave., N.W. (7407)
Washington, DC 20460
Phone: 202-260-1023
Fax: 202-260-4659
E-mail: PPIC@epa.gov
www.epa.gov/opptintr/library/ppicdist.htm

Information Products from DfE

Surface Finishes

PWB Surface Finishes: Cleaner Technologies Substitutes Assessment, EPA 744-R-01-003A and B
Implementing Cleaner Printed Wiring Board Technologies: Surface Finishes, EPA 744-R-00-002

Making Holes Conductive

Alternative Technologies for MHC: Cleaner Technologies for PWB Manufacturers, EPA 744-R-98-002
Cleaner Technologies Substitutes Assessment: Making Holes Conductive, EPA 744-R-98-004A and B
Implementing Cleaner Technologies in the PWB Industry: Making Holes Conductive, EPA 744-R-97-001

General PWB Information

PWB Pollution Prevention and Control Technology: Analysis of Updated Survey Results, EPA 744-R-98-003
PWB Industry and Use Cluster Profile, EPA 744-R-95-005
Integrated Environmental Management Systems Implementation Guide, EPA 744-R-00-011
Federal Environmental Regulations Affecting the Electronics Industry, EPA 744-R-95-001
Pollution Prevention Work Practices, PWB Case Study 1, EPA 744-R-95-004
On-Site Etchant Generation, PWB Case Study 2, EPA 744-R-95-005
Opportunities for Acid Recovery and Management, PWB Case Study 3, EPA 744-R-95-009

Plasma Desmear, PWB Case Study 4, EPA 744-R-96-003
A Continuous-Flow System for Reusing Microetchant, PWB Case Study 5, EPA 744-R-96-024
Pollution Prevention Beyond Regulated Materials, PWB Case Study 6, EPA 744-R-97-006
Building an Environmental Management System, PWB Case Study 7, EPA 744-R-97-009
Identifying Objectives for Your EMS, PWB Case Study 8, EPA 744-R-97-010
Flexible Simulation Modeling of PWB Costs, PWB Case Study 9, EPA 744-F-99-004

Internet Sites

DfE Printed Wiring Board Project
www.epa.gov/opptintr/dfe/pwb/pwb.html
Contains project documents and information.

Printed Wiring Board Resource Center
www.pwbrc.org/
Developed by the National Center for Manufacturing Sciences (NCMS) in partnership with IPC, with funding from EPA. Provides PWB industry-specific regulatory compliance and pollution prevention information.

IPC Lead-Free Web Site
www.leadfree.org/
Developed by IPC; describes industry research and initiatives, as well as marketing and legislative news, in areas relating to lead-free electronics.

University of Tennessee Center for Clean Products and Clean Technologies
eerc.ra.utk.edu/clean/
Provides information on the Center for Clean Products and Clean Technologies at the University of Tennessee in Knoxville.

Trade Associations and Research Institutions

IPC — Association Connecting Electronics Industries
2215 Sanders Road
Northbrook, IL 60062-6135
phone: 847-509-9700
fax: 847-509-9798
www.ipc.org

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600 Henley Street, Suite 311
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fax: 423-974-1838
eerc.ra.utk.edu/clean/