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Pollution Prevention Opportunity Assessment for the Electronics Prototype Laboratory

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Abstract

This Pollution Prevention Opportunity Assessment (PPOA) was conducted for Sandia National Laboratories/California Electronics Prototype Laboratory (EPL) in May 2005. The primary purpose of this PPOA is to provide recommendations to assist Electronics Prototype Laboratory personnel in reducing the generation of waste and improving the efficiency of their processes. This report contains a summary of the information collected, analyses performed and recommended options for implementation. The Sandia National Laboratories Pollution Prevention staff will continue to work with the EPL to implement the recommendations.

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Executive Summary

The Electronics Prototype Lab (EPL), located at Sandia National Laboratories/California (SNL/CA), produces various types and sizes of printed wiring boards (PWB) for internal customers. EPL personnel are concerned about the waste they generate. The EPL is the largest generator of hazardous waste at SNL/CA. This Pollution Prevention Opportunity Assessment (PPOA) was conducted to provide recommendations for possible waste reduction measures primarily for hazardous and California-regulated waste streams. The PPOA team consisted of personnel from Pollution Prevention (P2), the EPL, and the 910-waste water operations. This assessment team was responsible for evaluating processes and waste streams and generating the P2 opportunities identified in this report.

The largest waste streams generated from the EPL are from its chemical process line or Plating Facility. These are chemical baths that require a change-out when the chemistry has expired or it has become contaminated. The PPOA team evaluated waste stream data and potential waste reduction ideas for feasibility, applicability, and return on investment. Based upon this evaluation, three opportunities were selected for more in depth cost-benefit analysis. When implemented, these opportunities will reduce the generation of hazardous waste, reduce regulatory liability and reporting requirements, reduce personnel exposure to hazardous materials, improve operating efficiency, and provide a reasonable payback period on the initial investment in new equipment. The opportunities are as follows:

Opportunity 1: Optimization of Electroless Copper Bath

Opportunity 2: Photoresist Filtration from Dual Stripper Bath

Opportunity 3: Plasma Desmear System

The Plating Facilities current approximate cost of $120,000 per year in waste costs can be reduced by approximately $65,000 per year by implementing these 3 opportunities. The cost of implementation of the opportunities is estimated at $25,000.

Acronyms and Abbreviations

CNC	Computer Numerical Control Drilling Equipment
EPL	Electronics Prototype Laboratory
FY	Fiscal Year
KOH	Potassium Hydroxide
LECS	Liquid Efficiency Control System
MEA	Monoethanoamine
P2	Pollution Prevention
PPE	Personal Protective Equipment
PPOA	Pollution Prevention Opportunity Assessment
PWB	Printed Wiring Board
ROI	Return on Investment
SMOBC	Solder-mask-over-bare-copper
SNL/CA	Sandia National Laboratories/California
SNL/NM	Sandia National Laboratories/New Mexico
TCE	Trichloroethylene
VOC	Volatile organic compound

1.0 Introduction

The Pollution Prevention (P2) staff of Sandia National Laboratories/New Mexico (SNL/NM) conducts pollution prevention opportunity assessments (PPOAs) for Sandia organizations. The goal of a PPOA is to identify practical, cost-effective strategies to do one or more of the following:

- Reduce overall resource use
- Reduce or eliminate the generation of waste
- Reduce waste volumes and toxicity
- Increase purchasing of environmentally preferable material
- Reduce energy and water consumption
- Reduce the line organization's operational costs
- Reduce regulatory liability
- Reduce personnel exposure to hazardous material

The completed PPOA is presented to the organization for implementation. The P2 staff will assist with implementation as much as possible through technical and administrative support and identifying funding options when necessary.

This PPOA was conducted for the Electronics Prototype Laboratory (EPL) at Sandia National Laboratories/California (SNL/CA) in May 2005. A preliminary assessment (*Initial Data Gathering and Opportunity Identification [Tasks 1 and 2*], SAND-2002-8476) of all waste generators at SNL/CA determined that EPL operations generate a significant amount of hazardous waste.

The primary purpose of this PPOA is to identify and recommend strategies and technologies to eliminate or reduce the hazardous waste streams generated by the EPL. For the purposes of this report, the term "hazardous waste" refers to both waste defined as hazardous by the Resource Conservation and Recovery Act as well as the Department of Toxic Substances Control.

The process used to perform this PPOA is outlined in Figure 1. This report contains a summary of the information collected, the analyses performed, and recommended options for implementation. P2 staff members from both SNL/NM and SNL/CA will work closely with the EPL to implement these options.

The PPOA team consisted of staff members from P2, the EPL, the Photo Lab, and the 910-Waste Water Facilities. All EPL wastes streams were reviewed yet the primary focus of the PPOA is focused on the EPL's Plating Facility. The Plating Facilities process line is the largeste generator of hazardous waste at the EPL. This assessment team was responsible for evaluating processes and waste streams and generating the P2 opportunities identified in this report. Information was collected through interviews with facility personnel, site visits, evaluation of waste disposal and purchasing databases, and data collected to meet air emissions permit requirements.

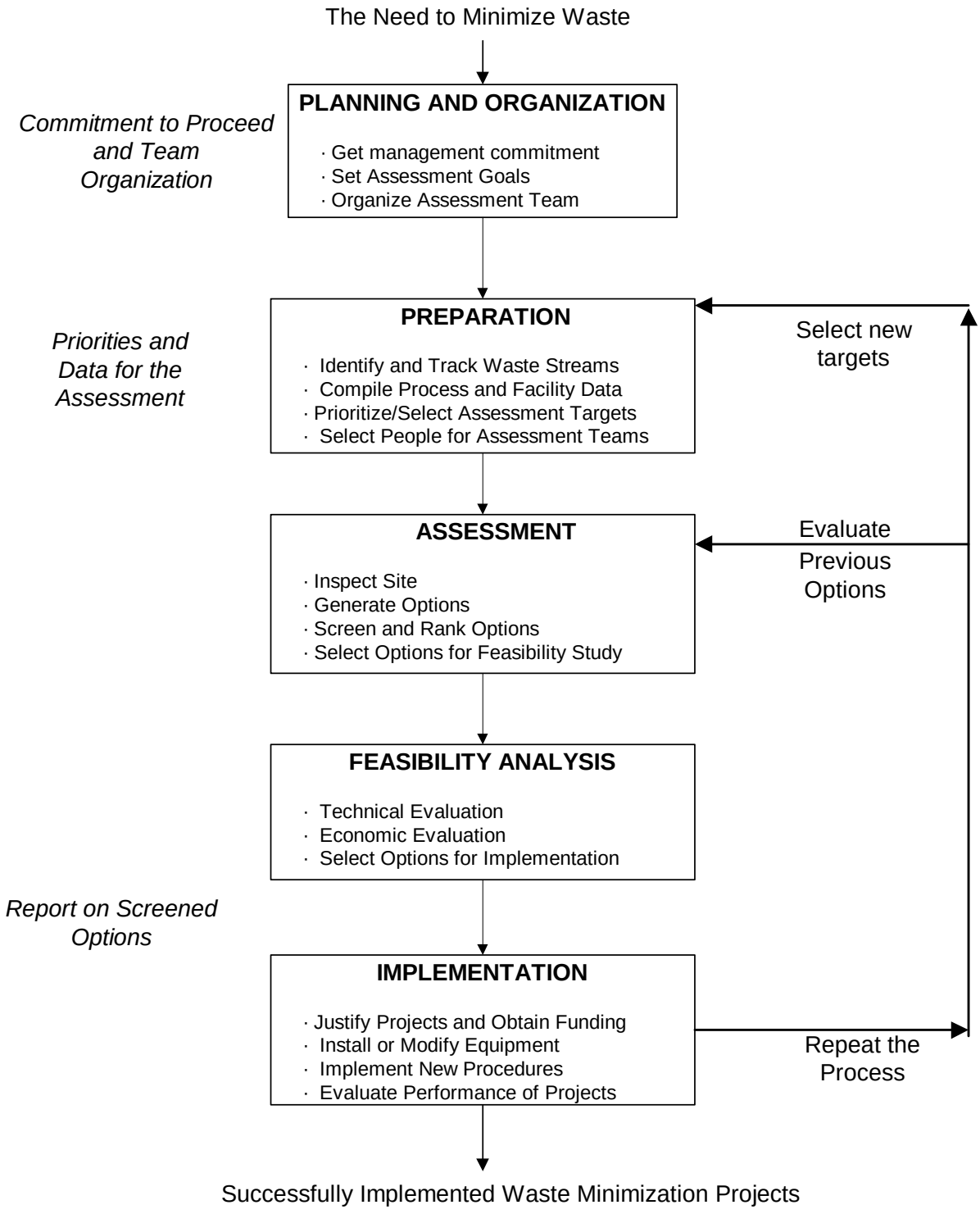

Figure 1: PPOA Process Diagram.

Alternatives identified through discussion and brainstorming with key personnel were then screened based upon feasibility and practicality. Finally, a cost-benefit analysis was performed on the selected alternatives to determine the costs and return on investment (ROI) for implementation.

2.0 Facility Description

Sandia established its California site in 1956 to support weapons engineering with its across-the-street neighbor Lawrence Livermore National Laboratory. SNL/CA employs slightly more than 1,000 persons, and its facilities consist of 60 buildings on 413 acres. The current fiscal year (FY) budget for SNL/CA is approximately $210 million.

Work performed at SNL/CA focuses on manufacturing-related research including microelectronics, nano-technologies, combustion research, materials synthesis and processing, materials characterization, process simulation, engineering theory and design, prototype fabrication, and demonstration techniques. Applications include welding technologies, semiconductor fabrication, sensors, high-performance metals, ultra-hard ceramic coatings, and computational modeling and analysis.

The EPL (Organization 8236-1), which is under the Engineering Services Department (Organization 8236) produces printed wiring boards, cables, and other electronic components for internal Sandia National Laboratories customers focusing on military and commercial research. The EPL is located in Building 910 and is a custom order process that builds electronic components from initial design concept to fully functional device.

The EPL staff consists of eleven full-time employees, three of which are responsible for the plating facility. The Plating Facility produces the majority of the SNL/CA waste and is the focus of this PPOA. Figure 2 presents the EPL's Plating Facility layout.

3.0 Assessment Methodology

This PPOA is one of a series of assessments to be performed at SNL/CA. A preliminary assessment (*Initial Data Gathering and Opportunity Identification [Task 1 and 2]* SAND2002-8476) ranked various SNL/CA organizations according to potential waste reduction opportunities. Criteria included high waste-generation rates, high probability for success, and ease of implementation. The EPL was targeted for further assessment based upon the quantities of waste generated and the likelihood that P2 opportunities could be implemented.

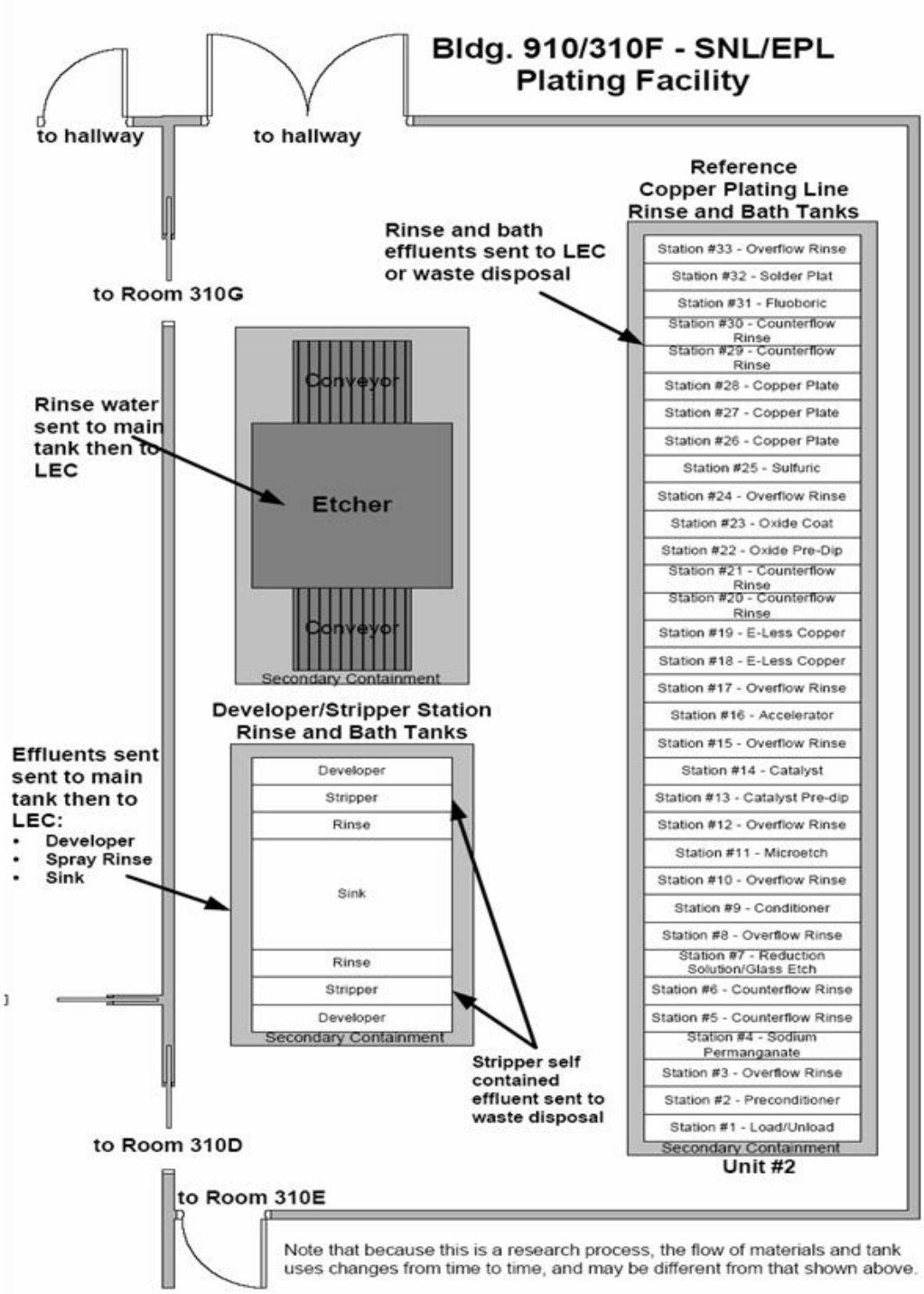

Figure 2: Electronic Prototype Laboratory (EPL) Plating Facility Layout

As depicted in Figure 1, the major steps of a PPOA include planning, preparation, assessment, feasibility analysis, and implementation. For this PPOA, the planning and preparation portion involved reviewing information from the initial assessment and identifying major waste streams generated by the EPL operations. The EPL has undergone several changes in the past few years. The original chemistry line and equipment was replaced by a new line in November 2003. New chemistries and process development occurred from February 2004 into April 2005. Only until recently has the process line performed adequately through chemistry evaluations. Therefore, waste data from the beginning of January through the end of July of 2005 were evaluated. It was deemed by the team that the 7 months provided an adequate data sampling to evaluate the lines processes.

The assessment phase consisted of a four-day site visit by a member of the SNL/NM P2 staff. During the visit, extensive interviews and discussions were held with personnel from the EPL, Photo Lab, and the 910-waste water operations. A site tour was conducted encompassing all EPL operations and activities. This phase focused on clarifying how waste is generated and encouraging personnel to share ideas about P2 opportunities.

In addition to the initial site visit, another visit to the site was conducted. The second visit provided a deeper look at particular processes. A chemical manufacturer was invited to tour the facility and elaborate on the initial findings. These findings and other opportunities were presented for information and discussion purposes to the EPL management staff and the PPOA team members.

The information from the assessment was compiled and descriptions of waste volumes and the accompanying processes refined. Additional sessions to gather information on the purchase and use of materials were conducted on the phone and via e-mail.

Once P2 opportunities were identified, each one was evaluated according to criteria that included technical feasibility, regulatory issues, and ROI. Both vendors and SNL/CA compliance personnel were consulted. The options that were satisfactory from a technical and regulatory standpoint were then analyzed for potential ROI. This is discussed in more detail in the cost-benefit analysis (Attachment 1).

Although the implementation phase is not included in this report, it is a key part of the process. P2 personnel from SNL/NM and SNL/CA will assist EPL management staff and personnel with implementation wherever possible. EPL will be expected to request funding for P2 opportunities and to take the lead on purchasing, installing, and operating new equipment. P2 personnel will also evaluate various funding sources and obtain funding when available. In addition, P2 staff will provide technical and regulatory assistance on an administrative level.

4.0 Waste Streams

At SNL/CA, the two most costly and frequently generated wastes are known as “hazardous” and “California regulated.” For the purposes of this report, these types of waste will be referred to collectively as hazardous waste. These wastes are tracked via database from the point of generation to disposal. The database contains extensive information on each waste container

including generating organization, contact, weight, and waste category. Generators are charged for the waste they generate. The charges vary from $1.00 to $28.00 per kilogram depending upon the volume and types of waste. Waste costs in this report are estimated based upon current disposal costs and may not reflect actual charges.

A waste stream can be defined as a waste with consistent characteristics that is generated from a specific process. All waste streams of the EPL are considered hazardous. The primary hazardous waste streams are depicted in the Pie chart in Figure 4 and for the most part, come from the EPL's Plating Facility. Every bath, with the exception of the rinse baths, is disposed of as hazardous waste. The EPL (Plating Facility) waste streams cost nearly $120,000 a year for disposal. Waste generated from the EPL accounts for approximately 53 percent of the sites total waste (see Figure 3) and about 41 percent of the total disposal costs. For these reasons, a separate PPOA was completed for the EPL.

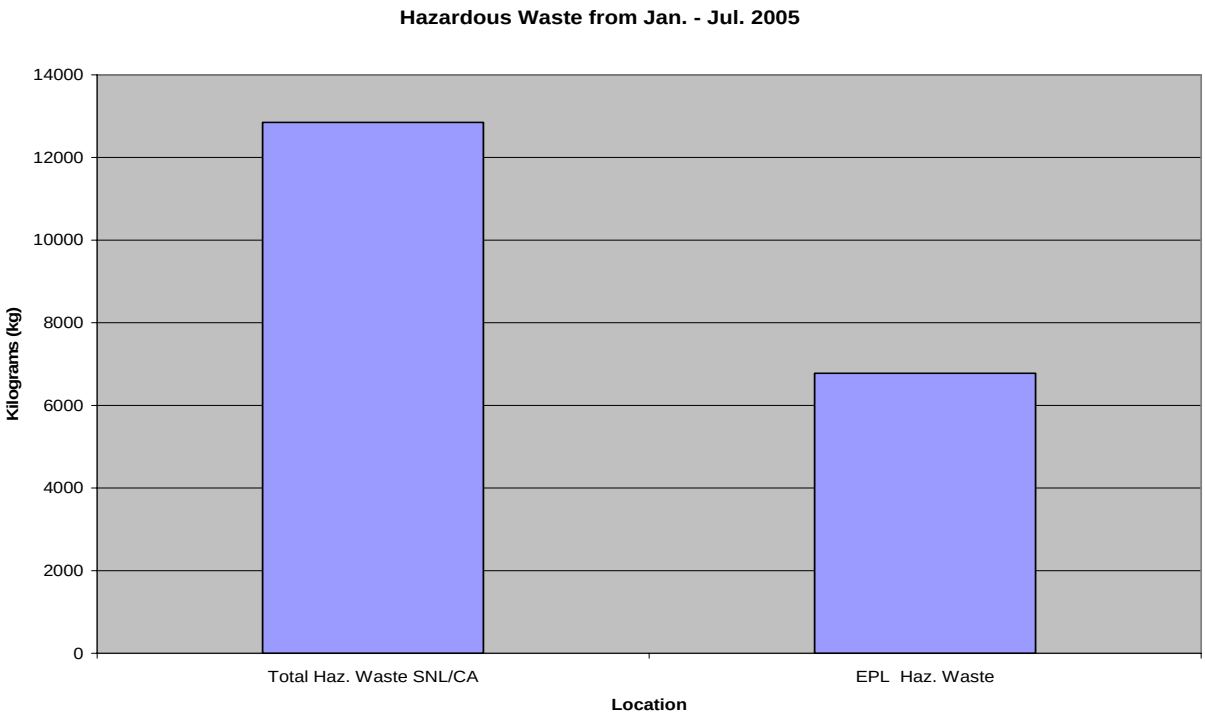

Figure 3: EPL hazardous waste versus the total of Sandia/CA hazardous waste (includes EPL waste)

4.1 Electronics Prototype Laboratory Processes and Wastes

Figure 4 lists major waste streams generated from the EPL processes and illustrates the comparative volume of each waste stream. The largest waste streams generated by the EPL come from its Plating Facility. This PPOA considered potential waste reduction ideas for each of these waste streams. Waste streams are comprised of single process baths and chemical baths that are staged together for an end result. The most effective ideas were created for the three waste

streams that together comprise 60 percent of the EPL's total waste. Figure 5 shows the average annual quantities in kilograms of these top three waste streams. Figure 6 shows the average annual costs associated with those quantities compared to the other waste streams of the EPL. The top three waste streams are:

- Electroless Copper Bath and Nitric Acid Cleaning Solution
- Dual Strip Bath (Photoresist Stripper)
- Etchback/ Desmear Process Baths

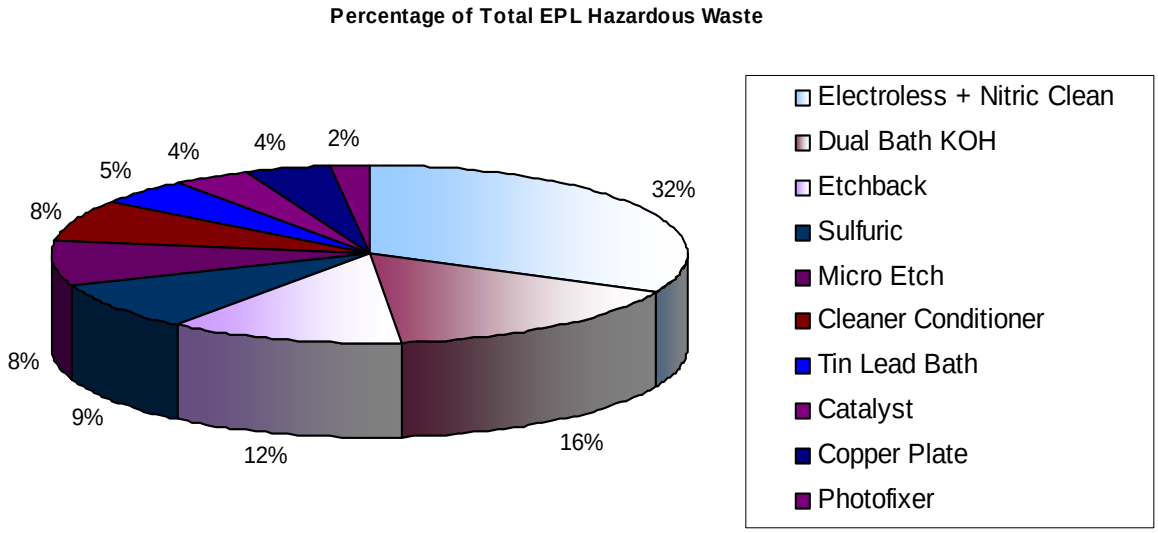

Figure 4: EPL Waste Streams.

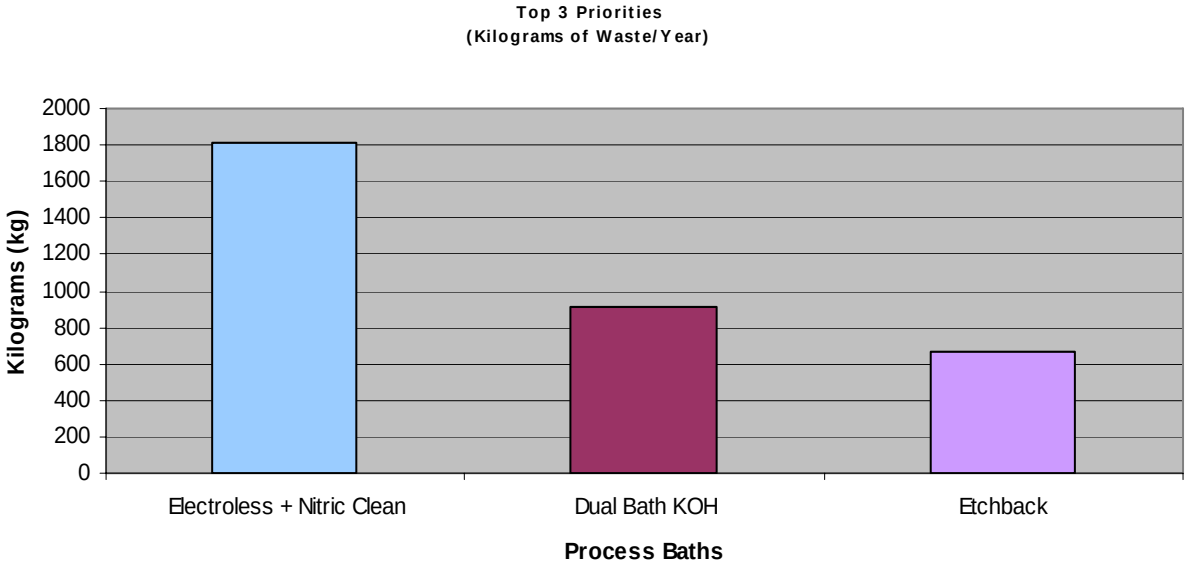

Figure 5: Quantities of Top Three EPL Waste Streams.

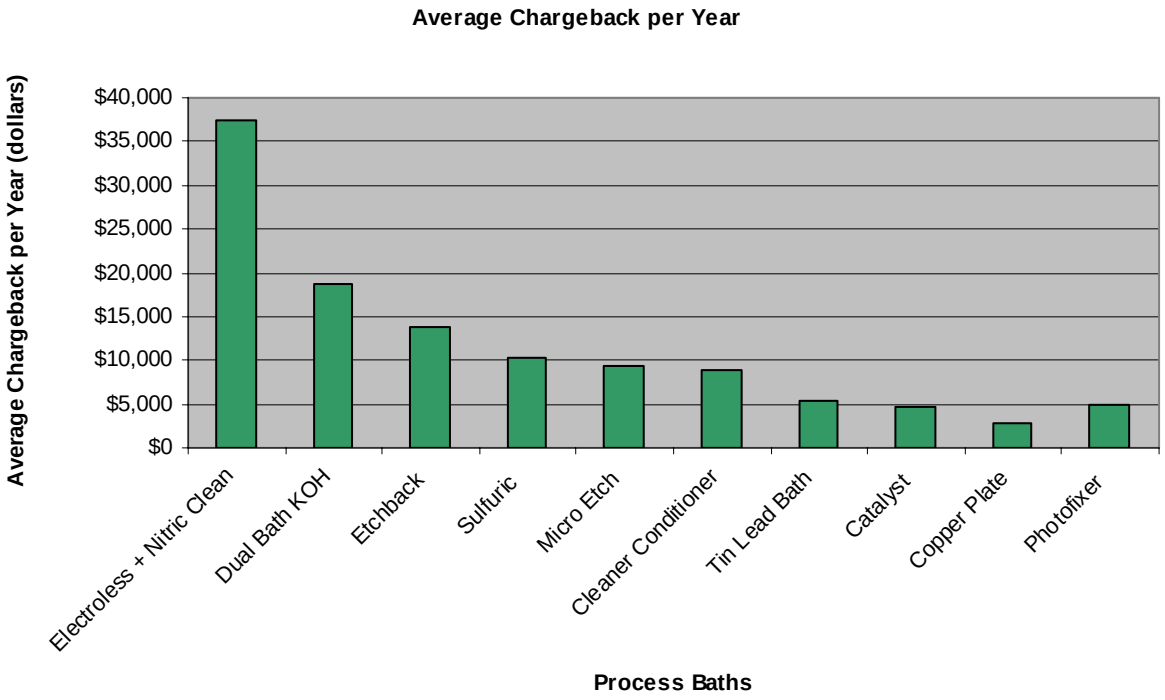

Figure 6: Average Annual Disposal Costs.

4.2 Overview of Printed Wiring Board Process

The printed wiring board (PWB) process at the EPL is a complicated process of many steps and process baths. The EPL is a custom order laboratory that is capable of fabricating various types (multilayer, flexible, rigid flexible, etc.) and sizes of PWBs. Although the process is dependent on the type of PWB to be processed, the process can be expressed in 9 generic steps (Figure 7).

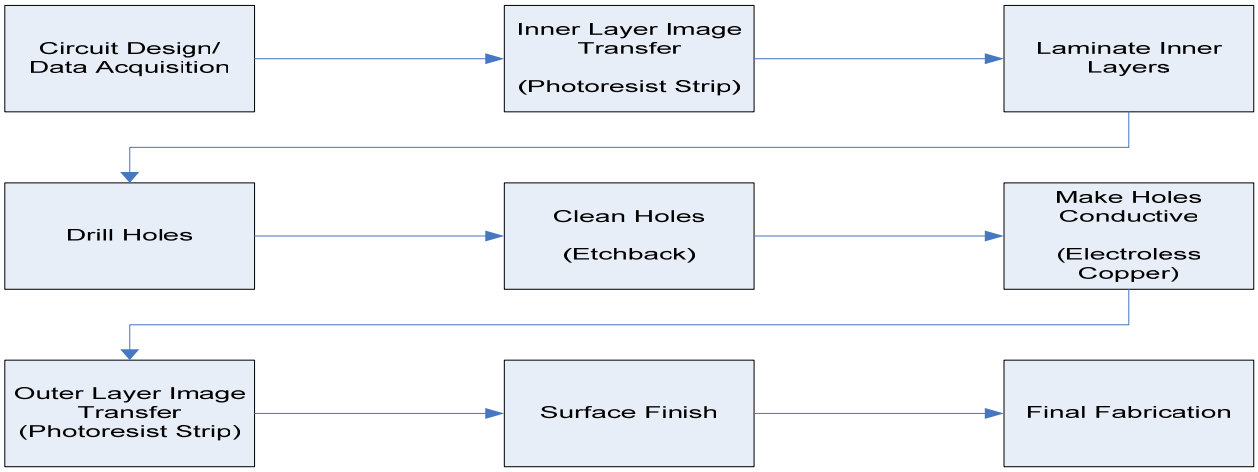

Figure 7: Generic Printed Wiring Board Process Steps

An overview of the 9 generic process steps is as follows:

- Circuit Design and Data Acquisition

Images of the PWB are received, manipulated, and edited to produce image files for the photo-tool.

- Inner Layer Image Transfer

A PWB laminate dielectric material sandwiched between copper foils is prepared. This material is then coated or laminated with photoresist where it is then exposed and developed. When completed an image is transferred to the photoresist. The panel is then etched to remove exposed copper. After etching, photoresist film stripping is performed. This reveals the protected copper image.

- Lamination

Lamination is the process of putting together various layers. This process involves stacking the inner layers and pressing them together.

- Drill Holes

Holes or vias are drilled through a PWB for the purpose of layer-to-layer interconnection. The holes are drilled with computer numerical control (CNC) drilling equipment and tungsten-carbide drill bits.

- Cleaning Holes

After the drilling step, the holes in the board must be cleaned. This process is called desmear and/or etchback. Desmearing refers to the removal of a small amount of epoxy-resin from the hole-barrel including any that may have been smeared across the copper interface during drilling. If the smear is not removed, interconnection between it and the electroless copper which is plated in the hole-barrel will be lost. Etchback is similar to the desmearing process but requires a significant amount of epoxy-resin and glass fibers be removed.

- Make Holes Conductive

To have layer-to-layer interconnection, the holes must be coated or plated with a conductive substance. Initially, a seed layer of copper is plated onto the hole-walls. The electroless copper process consists of four basic steps: cleaning, activation, acceleration, and deposition. The cleaning step begins with a cleaner-conditioner that removes organics, conditions the hole-barrels and prepares them for a catalyst and micro-etching step (activation and acceleration steps).

Following the activation and acceleration steps the holes of the board are coated with a light layer of copper in the electroless copper bath. This is a complex reaction of sodium hydroxide, formaldehyde and copper salt.

- Outer Layer Image Transfer

Outer Layer Image Transfer includes outer layer imaging, copper plating, etch-resist plating, etching and etch-resist stripping. Outer layer imaging is similar to inner layer imaging. After imaging, it is necessary to plate copper since the only areas coated in copper at this point in the process are the holes. Copper plating is used to plate onto the circuit pattern. This plated copper is now part of the finished product. After the copper is plated, a tin-lead etch resist is plated over the top of the copper. This allows for a protected layer over the copper pattern. Lastly, the photoresist film is stripped.

- Surface Finish

The Tin-Lead is reflowed to fully encapsulate the copper on the panel and create a more durable surface.

- Final Fabrication

Non-plated through-holes and other tooling features may be added to the circuit and the circuit itself is completely or partially de-panelized.

4.3 Electroless Copper and Nitric Electroless Cleaner Waste Stream

The Electroless Copper bath and its Nitric Electroless Cleaner Solution create the largest volume of waste at the EPL. The Electroless Copper bath alone ranks as the top waste stream. Every PWB is processed through the Electroless Copper bath. When the bath loses activation or copper has plated out on the sides of the bath it requires a change out and a cleaning with a nitric acid solution or Nitric Electroless Clean. On average, every three change-outs of the Electroless Copper bath fill a drum of the Nitric Electroless Cleaner for disposal. Together, these waste streams comprise approximately $37,000 annually in disposal costs. See Figure 6.

The Electroless Copper bath is one process step in an intricate 23 step Electroless Copper process line. The entire process line is used to prepare the PWB for the Electroless Copper bath by way of cleaning, activating, and accelerating. When the board is removed from the Electroless Copper bath, a thin coat of copper coats the holes of the board making the layers electrically interconnected.

The main constituents of the Electroless Copper bath chemistry are sodium hydroxide, formaldehyde, and copper salt.

4.3.1 Components of the Electroless Copper Bath

The Electroless Copper bath is the most complex bath in the entire PWB process line. There are several reasons why the Electroless Copper and Electroless Nitric Cleaner waste is the number one waste contributor at the EPL. The primary reason that the Electroless Copper requires frequent change-outs is that the chemistry is made to be a "workhorse". This statement is counter intuitive because most process baths require change-outs because the chemistries are depleted with continual work. It is not uncommon that a 31 gallon bath, such as the one at the EPL's Plating Facility, can produce 2000 sq. ft. of boards per day and last for a year before it requires a change-out. The EPL is considered a small shop with orders ranging from 30 to 50 sq. ft. of board per month yet currently has regular change-outs on a monthly basis. The EPL's low production requires an adjusted schedule of additions to optimize the baths parameters. Infrequent use of the bath creates different reactions of the constituents compared to a bath that is run constantly. There are two electroless copper baths on the EPL's Plating Facility line. The extra tank is used when the other tank is being cleaned which lasts between 1 and 2 days.

The main constituents of the electroless copper chemistry are sodium hydroxide, formaldehyde and copper salt. These constituents create a complex reaction. Formaldehyde is used to reduce the copper ion to metallic copper. Sodium hydroxide elevates the pH in the bath to enhance the reaction and the copper salt is used to react with formaldehyde to deposit copper in the boards' holes. This bath must be monitored frequently to ensure all of its ingredients are at optimum levels. Formaldehyde volatilizes, sodium hydroxide is broken down, and copper is deposited with or without board's running through the bath.

Since the EPL is a small custom shop, the baths are idle for periods of time. When idle, the electroless copper bath volatilizes formaldehyde through the aeration and water of the bath and sodium hydroxide continues to break down with a side reaction. Additives are required and must be in accurate quantities on a daily basis. Too little of the additives will not provide the concentration required of the process and will lose activation. Too much of the additives will facilitate "plate out" of copper on the sides of the bath and loss of copper and thus will lose activation. Currently, the EPL is not adding the appropriate concentrations of additives to maintain the bath life.

Lastly, stability of the bath is needed through aeration. The bath must have uniform small bubbles throughout the solution.

4.4 Dual Stripper Waste Stream

The Dual Stripper or photoresist stripper is the second largest waste stream at the EPL. The Dual Stripper is used in both the inner and outer layer image transfer steps. The purpose, as the name dictates, is to remove photoresist from the inner and out layers of the boards. Photoresist

stripping is simply an acid/base neutralization process. When this bath loses strength it is pumped to a drum for disposal. The annual disposal costs of this bath are nearly $19,000.

4.4.1 Components of the Dual Stripper Waste Stream

Photoresist is acidic and the stripping process neutralizes this acidity. In the process of neutralization, the alkalinity of the resist stripper is consumed. When this occurs, the photoresist of the boards is removed into the solution in fragments.

The constituents of the Dual Stripper are potassium hydroxide (KOH), monoethanolamine (MEA), and water. KOH is used to neutralize the charge of the hydroxide ion while the MEA takes the hydroxide molecule from a water phase to an organic phase. This facilitates the caustic solution to dissolve the photoresist.

The pH and temperature of the solution are also important. The higher the pH or alkalinity with a raised temperature, the more effectively the solution will react with the acidic photoresist.

When the photoresist of the board is removed into solution and remains in solution it is constantly worked on by this chemistry for complete neutralization. The Dual Stripper bath at the EPL is approximately 21 gallons of solution. When water is evaporated from the solution more water is added.

4.5 Etchback Process Waste Stream

The third largest waste stream at the EPL is the Etchback and Desmear process which consists of three baths. These baths are the Sweller/Sensitizer, Permanganate, and a Neutralizer. This process is used to clean the holes of the PWB which contain epoxy resins and smeared copper after drilling. This processes disposal costs are approximately $14,000 per year.

4.5.1 Components of the Etchback Process Waste Stream

Each PWB uses the etchback process to remove epoxy resin from the hole-barrel and any copper that may have smeared across the copper interface during drilling. The EPL runs the PWB's through these three baths in sequence three times. Due to custom specifications, the board requires a removal of a significant amount of epoxy resin and glass fibers.

The Sweller/Sensitizer is used to condition the subsequent removal of the epoxy resin smear. The second bath is Permanganate which oxidizes the epoxy resin and glass fibers. The final bath is the Neutralizer which removes the permanganate from the holes and the surface of the board.

The change-outs of these baths only occur one to two times a year, yet the disposal costs for the permanganate solution are significant due to its oxidizing characteristics.

5.0 Pollution Prevention Ideas and Opportunities

After evaluating the waste stream data, a list of potential waste reduction ideas were developed. All ideas, with the exception of Idea 6, are related to the EPL's Plating Facility. The ideas identified and evaluated are summarized below:

- Idea 1: Optimization of the Electroless Copper bath
- Idea 2: Photoresist Filtration for Dual Strip Bath
- Idea 3: Eliminate Etchback wet process by using Plasma Etchback/Desmear
- Idea 4: Utilize Statistical Process Control (SPC) for process optimization
- Idea 5: Substitute Electroless Copper process with an alternative process
- Idea 6: Substitute TCE with a biobased cleaner
- Idea 7: Extract Silver from Photofixer
- Idea 8: Utilize spent acid/base baths to assist neutralization of LECS
- Idea 9: Substitute Tin-Lead process with a non-lead process

Ideas 4 through 9 were rejected for the following reasons:

- Idea 4: Statistical Process Control (SPC) is an important aspect of process optimization. Even though it is not considered an opportunity for implementation at this time, its application to the process line should be considered in the future for process improvements. Use of SPC control charts are effective for the following reasons:

  - Directing attention on detecting and monitoring process variation over time
  - Helps distinguish special from common causes of variation
  - Serves as a tool for ongoing control of the process
  - Helps improve a process to perform consistently and predictably for higher quality, lower costs, and higher effective capacity.
  - Will provide a common language for discussing process performance.

- Idea 5: Both the Graphite-based and Palladium-based alternatives to the Electroless Copper process were reviewed and researched. The electroless copper line contributes a significant portion of the EPL's overall hazardous waste. The electroless copper line, inclusive of the electroless copper bath, is the largest generator at the EPL. Water use is also high due to critical rinsing required between nearly all of the process steps. Copper is often introduced into the waste water stream through the rinse baths. This requires special filtration through the Liquid Efficiency Control System (LECS) for waste water operations.

- The Graphite-based alternative is called Shadow® from Electrochemicals. The Graphite-based system uses graphite particles suspended in colloid that then acts as a conductive pathway for electroplating. Only four specific process steps are required, compared to the 23 steps in the current electroless process at the EPL's Plating Facility. Unfortunately, this process still needs to be proven. Sandia/NM used the Shadow® process in their PWB process and had trouble receiving consistent results. Until this process has been proven and optimized, the electroless copper line will be used.

- The Palladium-based alternative was also researched. The benefits of the Palladium-based process are that it completely removes formaldehyde from the process, it reduces the amount of water consumed to make the drill holes conductive, and therefore reduces the amount of wastewater generated. This process was rejected for two reasons. In the past the Kansas City Plant tried to use this process and they were not satisfied by its performance. Secondly, a new palladium line would cost as much as a new Electroless Copper line.

- Idea 6: For the purposes of this PPOA, the Trichloroethylene (TCE) waste stream is not significant with only 4kg disposed of over a 7 month period. TCE is used to clean flux from the boards during final fabrication. TCE is a very good cleaning solvent but is a Volatile Organic Compound (VOC) and is toxic. Sandia/NM substituted TCE with a terpene based cleaner. There are several other biobased alternatives to TCE. This idea should not be completely rejected but requires further research and experimentation.

- Idea 7: Photofixer accounts for 2% of the EPL's waste and was not considered a top priority for waste stream. Silver is a valuable resource and should be recycled. The silver can be recovered at the EPL but will require the purchase of a metallic replacement system. A metallic replacement system is the most suitable recovery system for the EPL since the waste is relatively small compared to larger shops. Unfortunately, this system is only capable of recovering 95% of the silver in the photofixer solution. This would cause concern in the disposition of its remaining waste. Additionally, the quantity of silver flake created would require a great length of time to be considered valuable to a refiner. Another idea is to outsource to a refiner/recycler.

- Idea 8: Utilizing the spent baths, such as the Sulfuric bath (acid) and the Condioner/Cleaner (base), to assist in neutralizing the water waste at the LECS was rejected. The basis of rejection was that the spent baths would be too contaminated with copper and other contaminants to be used for neutralization. Unless these baths are filtered of their contaminants it would not be useful to use them for this task. The quantity of acid solution and base solution used for neutralization at the LECS is minimal as well.

- Idea 9: The Tin-Lead bath substitution was rejected because it is not a large waste contributor and is still required as part of the work at the EPL. The bath consists of fluoboric acid, tin and lead fluoborate, and proprietary organic additives. The concern with the reflowed tin-lead is the lead. The regulatory status of lead varies but is increasingly scrutinized. The EPL is unable to eliminate tin-lead plating because a certain percentage of the work still requires a reflowed finish. Some military specifications continue to call for

tin-lead reflow. When, and if, these conditions change, as an etch-resist, there is no difference in the performance of tin or tin-lead. Tin-lead can be phased out by simply replacing the tin-lead anodes concentration to gradually fall or by replacing the bath with tin sulfate. Another option is solder-mask-over-bare-copper (SMOBC) which is a surface finishing method. Tin-lead plating has become unnecessary for most panels so SMOBC is a worthwhile option. Again, a certain percentage of customers require the reflowed finish of tin-lead so this process would have to be run in parallel at this time.

Ideas 1 through 3 were selected for additional investigation and became three opportunities recommended for implementation. A cost-benefit analysis (see Attachment 1) was performed for all three Opportunities, which involve capital equipment purchases. Each opportunity is discussed in Chapter 6, and all three opportunities are recommended for implementation. These opportunities show annual cost savings with quick payback periods and significant reductions in hazardous waste and material purchases.

6.0 Description and Analysis of P2 Opportunities

6.1 Opportunity 1: Optimization of the Electroless Copper Bath

The first key to extending the life of the Electroless Copper Bath is to have an accurate schedule of constituent additions to the bath. The EPL uses the bath periodically and it can remain idle for days. This creates a new dynamic on how the bath should be maintained.

The EPL has been adding excessive amounts of chemicals based on a bath that is continuously used on a daily basis. The addition of too many chemicals typically uses up all the formaldehyde, plates out copper in the bath, and uses up the sodium hydroxide by way of side reactions.

To gain proper maintenance and control of the bath a method of measuring the baths constituents is necessary. This consists of a colorimetric kit, a titration procedure, and a pH probe or monitor. The colorimetric kit is supplied by the manufacturer and tests for copper content of the bath. The titration procedure will be used to determine the sodium hydroxide and formaldehyde content of the bath. Lastly, the pH probe or monitor will determine the pH levels of the bath.

Furthermore, the Electroless Copper bath volume is excessive. A bath this size, according to the manufacturer of the chemistry, is made for loads of 15 sq. ft. of boards per run (i.e. 15-1ft. x 1ft, 1-3ft.x 5ft., etc.). The EPL lab currently runs 30 sq. ft. of board per month. Therefore, the bath volume can be reduced to at least 50% of its current volume. Longer clamps on the automatic line can ensure the typical sized board (12”x 18”) is submerged in solution. The EPL currently owns longer clamps.

Lastly, stability of the bath is provided by air spargers. The bath should have uniform small bubbling throughout the tank. Currently, the EPL has one air sparger in the bath which does not provide uniform bubbling throughout the bath. An additional air sparger is required for the bath to provide uniform bubbling and stabilization.

Current annual average disposal costs for the Electroless Copper and Nitric Electroless Clean is $37,000. Maintaining the bath properly and reducing the volume to 50%, would reduce the waste generated by approximately 87 percent, reducing costs by $32,190 per year. Approximately 80 gallons of Electroless Copper and Nitric Acid are purchased each year at a cost of $1660. These costs would also be reduced by approximately 87 percent showing an annual savings in purchase costs of nearly $1440.

6.2 Opportunity 2: Photoresist Filtration for Dual Strip Bath

Filtering the photoresist from the dual stripper at the end of each day or after a custom order will extend the life of the bath by 4 to 6 times. A 1 horse-power pump, an adequately sized compatible container, and a 200 micron screen are used to filter the photoresist. The filtered solution is then re-introduced to the bath for extended use.

A lab scientist at ChemCut Corporation, a wet processing equipment manufacturer, performed an experiment to validate that photoresist filtration is necessary to extend a dual strippers bath life. The scientist was able to extend the life of a bath from 2 weeks (non-filtered) to 2-3 months (filtered) by removing photoresist at the end of each day.

In addition to filtration, the pH of the bath should be maintained for optimal performance. Evaporation occurs readily due to the high temperature and water content of the bath. After filtration is performed or when the addition of water is required to fill the tank, the pH should be measured with a pH probe or monitor. The pH should be between 11 and 13 for optimal performance. Addition of the Dual Strip chemistry can raise the pH of the bath for optimal performance when more water is needed.

Current annual average disposal costs for the Dual Strip bath is $18,800. Filtering the photoresist from the bath and maintaining the pH, would allow the waste generated to be sent directly to the LECS for neutralization except for the filtered photoresist removed from the solution. This reduces the waste generated by approximately 92 percent, reducing costs by $17,300 per year. Approximately 42 gallons of Dual Stripper are purchased each year at a cost of $462. These costs would also be reduced by approximately 75 percent showing an annual savings in purchase costs of nearly $346.

6.3 Opportunity 3: Plasma Desmear System

This opportunity eliminates the use of the etchback wet process at the EPL. Using plasma to desmear and/or etchback eliminates the etchback wet process (sweller/sensitizer, permanganate, and neutralizer/glass etch), reduces chemical disposal cost, and reduces water use and treatment costs. With plasma etching the panels are placed in a vacuum chamber, and gas is introduced and converted to reactive plasma by a power supply. The plasma reacts at the panel surface and volatile by-products (resin smear) are removed by the vacuum pump.

The addition of relatively inert gases, such as nitrogen or argon, stabilizes the plasma and controls the rate of ionization. Reactive oxygen species oxidize organic contaminants on the surface, creating volatile species that are pumped away. Etch rates are increased by providing

more reactive species in the form of fluorine such as F_2, CF_4, or CHF_2. Adjusting etch rates and setting up recipes on the Plasma Desmear System will duplicate the etchback removals required of the existing wet process.

This system was used in the PWB process at Sandia/NM to their satisfaction. They were pleased with the performance of the system.

Eliminating the use of the Etchback wet process relinquishes three chemical baths. The availability of these three baths will allow the EPL to develop other processes, such as alternatives to Electroless Copper. Exposure to the hazardous materials will also be reduced by eliminating the wet process and utilizing the plasma desmear process.

The Plasma Desmear System does require upgrades in cables, the computer, and software to function properly. Additionally, the EPL staff will require training on the use and creation of recipes of the system.

Implementing this opportunity will eliminate the disposal and purchase of the etchback wet chemistries. This is a savings of approximately $14,000 in disposal charges and $3750 in raw materials per year and removes 12% of the EPL's hazardous waste stream.

7.0 Conclusion

The three opportunities identified in this report can significantly reduce the cost and waste generation rates for the EPL. Given the significant potential for ROI on the equipment investments, it is recommended that the opportunities be implemented. All three opportunities will require zero down time of the current process to ensure orders are completed on time. Opportunity 1 and 2 involves changes in administrative operations, procedures, and relatively inexpensive equipment purchases that could be adopted by the EPL and once trained, effective within a couple months. Opportunity 3, allows for the current operation to proceed while the system is upgraded and experiments are performed for process optimization. In addition, by implementing these three recommendations, the EPL will reduce its regulatory liability and reporting requirements while achieving improved operating efficiency for the EPL staff.

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ATTACHMENT 1

Cost-Benefit Analysis

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Option: Optimization of Electroless Copper Process

Worksheet 1: Operating and Maintenance Annual Recurring Costs

Expense Cost Items	Before (B) Annual Costs	After (A) Annual Costs
Equipment		
Purchased Raw Materials and Supplies		$0
Process Operation Costs:		
Utility Costs		
Labor Costs		
Routine Maintenance Costs for Processes		$175
Process Costs	$1,656	$715
Other		
Subtotal	$1,656	$890
PPE and Related Health/Safety/Supply Costs		
Waste Management Costs:	$37,337	$4,667.13
Waste Container costs		
Treatment/Storage/Disposal Costs		
Inspection/Compliance Costs		
Subtotal	$37,337	$4,667
Recycling – Material Collection/Separation/Preparation Costs:	$0	$0
Material and Supply Costs		
Operations and Maintenance Labor Costs		
Vendor Costs for Recycling		
Subtotal	$0	$0
Administrative/Other Costs		
Total Annual Cost:	$38,993	$5,557

Worksheet 2: Itemized Project Funding Requirements (One-Time Implementation Costs)

Category	Cost $
INITIAL CAPITAL INVESTMENT	$2,250
Design	
Purchase	
Installation	
Other Capital Investment (explain)	
Subtotal: Capital Investment = (C)	$2,250
INSTALLATION OPERATING EXPENSES	
Planning/Procedure Development	$250
Training	$250
Miscellaneous Supplies	
Startup/Testing	
Readiness Reviews/Management Assessment/Administrative Costs	
Other Capital Investment (explain)	
Subtotal: Installation Operating Expenses = (E)	$500
All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.)	
Total Project Funding Requirements = (C + E)	$2,750
Useful Project Life (L) (Years)= 10	Time To Implement (Months)= 3
Estimated Project Termination/Disassembly Cost (if applicable) (D) =	
RETURN ON INVESTMENT CALCULATION	
ROI = (B – A) – [(C + E + D)/L] x 100 =	1205.85%

O&M Annual Recurring Costs		Project Funding Requirements	
Annual Costs, Before (B) =	$38,993	Capital Investment (C) =	$2,250
Annual Costs, After (A) =	$5,557	Installation Op Expenses (E) =	$500
Net Annual Savings (B – A) =	$33,436	Total Project Funds (C + E) =	$2,750

Electroless Copper Optimization

Worksheet 3: Estimate Basis

ASSUMPTIONS FOR ELECTROLESS COPPER

The costing analysis uses several assumptions. The main assumption is that the bath will be reduced in volume by 50% and that a manual titration analysis will be performed to assess the percent content of each of the constituents in the bath. This titration analysis will provide the important additions of chemistries to optimize the bath performance and extend its life. This simple cost analysis neglects administrative and/or negligible or minor cost items.

EXISTING TECHNOLOGY

The Electroless Copper bath uses 3 gallons of CD755A and 3 gallons of CD755B per bath. In addition, Nitric Acid is used to clean the bath when it is cleaned out. It is estimated that each Electroless Copper bath uses 1.75 liters of Nitric Acid per clean. CD755A costs $14/Gal, CD755B is $55/Gal, and the Nitric Acid costs $23/ Liter. The total gallons per year of CD755A and CD755B are approximately 72. The Nitric Acid use per year is 21 Liters.
Waste management costs are based upon the average annual generation rate of chemical waste and are considerable at approximately $37,337.

PROPOSED P2 TECHNOLOGY

The initial capital investment is the purchase of a pH probe, titration lab ware, and titration chemicals.

Chemical Costs for Titration: $500 (Chemicals Listed in Attachment 2)
Equipment Costs: $1750 (Equipment Listed in Attachment 2)

Process Costs: Titration/Analysis chemicals will need to be purchased on an annual basis for approximately $500. Approximately 13% of the original Electroless Copper chemistries will need to be purchased which comes to approximately $215 per year. Additionally, it is assumed that replacements of lab ware will be needed and were estimated to be 10% of the initial cost of equipment per year at $175.

Procedures/Training: A procedure and training is a requirement to standardize the use of the titration equipment. It was assumed this would take 2 days and would cost approximately $500.

COST SAVINGS, COST AVOIDANCE, AND RISK REDUCTION

Cost savings are based mainly on the reduction of waste generation. The purchasing of process chemicals was also reduced by approximately 50%.

Option: Filtration System for Dual Strip (photoresist stripper)

Worksheet 1: Operating and Maintenance Annual Recurring Costs

Expense Cost Items	Before (B) Annual Costs	After (A) Annual Costs
Equipment		
Purchased Raw Materials and Supplies	$462	$116
Process Operation Costs:		
Utility Costs		
Labor Costs		
Routine Maintenance Costs for Processes		
Process Costs		
Other		
Subtotal	$462	$116
PPE and Related Health/Safety/Supply Costs		
Waste Management Costs:	$18,800	$1,500
Waste Container costs		
Treatment/Storage/Disposal Costs		
Inspection/Compliance Costs		
Subtotal	$18,800	$1,500
Recycling – Material Collection/Separation/Preparation Costs:	$0	0
Material and Supply Costs		
Operations and Maintenance Labor Costs		
Vendor Costs for Recycling		
Subtotal	$0	$0
Administrative/Other Costs		
Total Annual Cost:	$19,262	$1,616

Worksheet 2: Itemized Project Funding Requirements (One-Time Implementation Costs)

Category	Cost $
INITIAL CAPITAL INVESTMENT	
Design	
Purchase	$2,000
Installation	
Other Capital Investment (explain)	
Subtotal: Capital Investment = (C)	$2,000
INSTALLATION OPERATING EXPENSES	
Planning/Procedure Development	
Training	
Miscellaneous Supplies	
Startup/Testing	
Readiness Reviews/Management Assessment/Administrative Costs	
Other Capital Investment (explain)	
Subtotal: Installation Operating Expenses = (E)	$0
All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.)	
Total Project Funding Requirements = (C + E)	$2,000
Useful Project Life (L) (Years)= 10	Time To Implement (Months)= 2
Estimated Project Termination/Disassembly Cost (if applicable) (D) =	
RETURN ON INVESTMENT CALCULATION	
ROI = (B – A) – [(C + E + D)/L] x 100 =	872.33%

O&M Annual Recurring Costs		Project Funding Requirements	
Annual Costs, Before (B) =	$19,262	Capital Investment (C) =	$2,000
Annual Costs, After (A) =	$1,616	Installation Op Expenses (E) =	$0
Net Annual Savings (B – A) =	$17,647	Total Project Funds (C + E) =	$2,000

Filtration for Dual Strip (photoresist stripper)

Worksheet 3: Estimate Basis

ASSUMPTIONS FOR FILTRATION OF THE DUAL STRIP

The main assumptions are that the photoresist fragments are filtered from the solution and the solution is diluted and neutralized at the LEC. This simple cost analysis neglects administrative and/or negligible or minor cost items.

INITIAL CAPITAL INVESTMENT

There are three essential parts to the initial capital investment. A one-horsepower pump that is compatible with the chemistry is required, a drum that is capable of managing 21 gallons of solution, and a 200 micron 316SS mesh filter or something similar. The cost of this equipment was estimated based on manufacturer's information. The filter mesh costs $52/sq. ft. from ChemCut Corporation.

EXISTING TECHNOLOGY

Currently 7 Gallons of Dual Stripper solution is added to each bath which is $77/bath or $462/year. The process is dumped when it is no longer active. The waste management costs are approximately $18,800 per year.

PROPOSED P2 TECHNOLOGY

The proposed P2 Technology cost assumes the cost of the pump, filter, and containment drum at $2000. The new technology will require additional labor on the part of the operator. The solution will need to be pumped to a container through the filter and re-pumped back into the bath on periodic or procedural basis. The photoresist fragments can be dried and placed in a waste container for disposal. It was assumed that one drum of waste (dryed photoresist fragments) would be required per year and cost $1500 for disposal.

COST SAVINGS, COST AVOIDANCE, AND RISK REDUCTION

Cost savings are based reduced purchases of chemicals and waste generation.

Option: Plasma Desmear System

Worksheet 1: Operating and Maintenance Annual Recurring Costs

Expense Cost Items	Before (B) Annual Costs		After (A) Annual Costs
Equipment			
Purchased Raw Materials and Supplies	$3,750		$3,000
Process Operation Costs:			
Utility Costs			
Labor Costs			
Routine Maintenance Costs for Processes			
Process Costs			
Other			
Subtotal	$3,750		$3,000
PPE and Related Health/Safety/Supply Costs			
Waste Management Costs:	$13,800		$0
Waste Container costs			
Treatment/Storage/Disposal Costs			
Inspection/Compliance Costs			
Subtotal	$13,800		$0
Recycling – Material Collection/Separation/Preparation Costs:	$0		$0
Material and Supply Costs			
Operations and Maintenance Labor Costs			
Vendor Costs for Recycling			
Subtotal	$0		$0
Administrative/Other Costs			
Total Annual Cost:	$17,550		$3,000

Worksheet 2: Itemized Project Funding Requirements (One-Time Implementation Costs)

Category			Cost $
INITIAL CAPITAL INVESTMENT			$20,000
Design			
Purchase			
Installation			
Other Capital Investment (explain)			
Subtotal: Capital Investment = (C)			$20,000
INSTALLATION OPERATING EXPENSES			$0
Planning/Procedure Development			
Training			
Miscellaneous Supplies			
Startup/Testing			
Readiness Reviews/Management Assessment/Administrative Costs			
Other Capital Investment (explain)			
Subtotal: Installation Operating Expenses = (E)			$0
All company adders (G&A/PHMC Fee, MPR, GFS, Overhead, taxes, etc.)			
Total Project Funding Requirements = (C + E)			$20,000
Useful Project Life (L) (Years)=	10	Time To Implement (Months)=	6
Estimated Project Termination/Disassembly Cost (if applicable) (D) =			
RETURN ON INVESTMENT CALCULATION			
ROI = (B – A) – [(C + E + D)/L] x 100 =			62.75%

O&M Annual Recurring Costs		Project Funding Requirements	
Annual Costs, Before (B) =	$17,550	Capital Investment (C) =	$20,000
Annual Costs, After (A) =	$3,000	Installation Op Expenses (E) =	$0
Net Annual Savings (B – A) =	$14,550	Total Project Funds (C + E) =	$20,000

Plasma Desmear System

Worksheet 3: Estimate Basis

ASSUMPTIONS FOR THE PLASMA DESMEAR SYSTEM

This simple cost analysis neglects administrative and/or negligible or minor cost items.

INITIAL CAPITAL INVESTMENT
There is a $20K installation cost. This installation involves the addition of new cabling, software, and an overall tune-up. Included in the price is also training for the operators of the equipment.

INSTALLATION AND STARTUP
Installation and start-up is shared in the initial capital investment cost.

EXISTING TECHNOLOGY
The existing technology is going to be eliminated by the new technology. The existing technology will be used until the new technology is efficient and optimized.

PROPOSED P2 TECHNOLOGY
The annual material cost for raw materials will not change significantly based on information provided by a Plasma Desmear manufacturer. Yet, there will not be disposal costs of the new technology since the gases used are not regulated. The material cost includes the purchase of CF4, oxygen, and inert gas bottles required for the recipes. The current cost of these bottles, based on current production, is $3000 per year.

COST SAVINGS, COST AVOIDANCE, AND RISK REDUCTION
Cost savings are based upon reduced waste production. Maintenance of the wet processing baths reduces safety risks substantially.

ATTACHMENT 2

Electroless Copper Opportunity Information

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Chemicals for titration analysis

Ammonium Hydroxide Aqua Ammonia → 2.0 Gal
Ammonium Chloride → 2.0 lbs
Reagent Grade l
Pan Indicator Solution (1%) → 2.0 Pints
0.05 M EDTA Solution → 2.0 Gal
0.1 Normal Hydrochloric Acid → 1..0 Gal

Lab Glass- Ware and Equipment for titration analysis

P. H. meter ----------Hanna- ---------- HI8314 with Electrode 2.0 each
Corning Stirer----------Cat. H-497-22- ----------2.0 AECH
Magnetic Bars ----------(½) ^{n} ---------- Cat14-511-61-Sae
Beakers ----------250 ML ----------Cat-10003-250 ------- 6 each
Beakers ----------400 ML----------Cat-10003-400 ------- 6 each
Beakers ----------1000 ML ----------Cat-10003-1000------ 6 each
Burets ----------Cat #03-846 BT---------- 6 each
Erlenmeyer Glass Flasks Cat 26650 ----------250 ---------- 12 each
Erlenmeyer Glass flasks Cat 26650 ----------500---------- 12 each
Volumetric Flask Cat 28017 ----------250---------- -12 each
Volumetric Flask Cat 28017 ----------500---------- 12 each
Volumetric Flask Cat 2801---------- 1000---------- 6 each
Volumetric Flask Cat 2801----------200---------- 4 each

Conical filter for adding chemicals
Stand for Burets

***Note: All catalogue numbers are from Fisher Book. Call H&R SuperChem you have any questions.**

ELECTROLESS COPPER CONTENT

1. **Pipette 20 mL sample into 250 mL flask.**
2. **Add 10 mL of DI water.**
3. **Add 25 mL of Ammonia Buffer.**
4. **Add 7 drops of PAN indicator and 5 drops of Acetic Acid**
5. **Titrate with 0.05 M EDTA to a clear-green end point.**

CALCULATIONS:

% Copper = mL of 0.05 M EDTA X 3.78
range (70% and 100%)
or
g/L Copper = mL of 0.05M EDTA X 0.16
range (2.9-3.8)

Preparation of Ammonia Buffer

Dissolve 70 g ammonium chloride in 500 ml D.I. water. Add approximately 40 ml of ammonium hydroxide solution (NH OH) to bring the solution to pH 10.0; dilute to 1.0 L and mix.

SODIUM HYDROXIDE CONTENT

1. **Pipette 5.0 mL sample into 150 mL beaker.**
2. **Add 100 mL DI water.**
3. **Using pH meter and 0.1 N HCl, Titrate to 10.0 pH.**

CALCULATIONS:

Gm/L of NaOH = ML of 0.1 N HCL X 0.8
Range (7.0 g/L to 9.0 g/l NaOH)

FORMALDEHYDE CONTENT

To the above solution add 1 gram of sodium sulfite; let it mix for 5 minutes. Using the pH meter and 0.1 N HCl, Titrate back to 10.0.

CALCULATIONS:

g/l HCHO = mL of 0.1 N HCl X 0.6
range (5.5-6.5)

8.0 TECHNICAL DATA SHEET

PACKAGING

H&R SuperChem ECP755-A, ECP755-B, ECP755-C and ECP755-D are available in 5-gallon pails and 55-gallon drums.

STORAGE & HANDLING

Store ECP755-A, ECP755-B, ECP755-C, and ECP755-D concentrates in sealed original containers in a dry area away from oxidants at 60°F to 90°F (15°C to 32°C). Do not store in direct sunlight. Do not allow to freeze.

SAFETY AND INDUSTRIAL HYGIENE

H&R SuperChem ECP755-A and ECP755-C contain formaldehyde, and ECP755-A contains a copper salt. Danger! May be fatal if swallowed. Harmful if inhaled or absorbed through the skin. Causes irritation to skin, eyes and respiratory tract.

Formaldehyde is a suspected carcinogen. Local exhaust ventilation is required. Workplace levels of formaldehyde should be kept below current ACGIH threshold limit values.

H&R SuperChem ECP755-B, ECP755-D and the electroless copper bath contain alkaline materials. These materials are corrosive and will cause burns to eyes and skin upon direct contact. Use safety goggles, gloves, protective clothing and approved respirators when working with these materials.

EMERGENCY AND SUGGESTED FIRST AID

In case of eye contact, immediately wash eyes by means of a continuously flowing stream of water directed into the eyes for at least 15 minutes. Seek medical attention immediately.

In the event of skin contact, wash skin thoroughly with soap and water. If irritation develops, get medical attention. Remove and launder contaminated clothing before re-use.

8.1.1.1.1 NOTE: Material Safety Data Sheets (MSDS) are available for H&R SuperChem

ECP755-A, ECP755-B, ECP755-C and ECP755-D upon request from:
H&R SuperChem, 7631 Woodwind Drive, Huntington Beach, CA 92647
Telephone (714) 848-8022; fax (714) 848-3577, or e-mail syedmhasan@aol.com or www.hrsuperchem.com

SNL/ CA

Electroless Copper Bath

In brief the electroless copper chemistry can be described in the following chemical formula:

$$Cu^{2+} + HCHO + 3OH \rightarrow Cu + HCOO + 2H_2O$$

The copper is used in the concentrate solution in the form of copper penta hydrate with 30% of formaldehyde solution, along with sodium hydroxide. Formaldehyde is used as a reducing agent in this solution and sodium hydroxide is used to maintain the pH between 12.5 and 13.5.

The following are a few of the established facts for running electroless copper solution:

1. Electroless copper solution must have moderate air agitation continuously
2. Formaldehyde volatilizes by air and its content should be maintained by frequent analysis.
3. pH of the solution gets to the lower level of the range if the solution is not in use regularly.
4. When formaldehyde content gets to the level of being lower than 3 grams per liter and sodium hydroxide being reduced to less than 4 grams per liter, there is a possibility of dark electroless copper deposit.
5. It is therefore, suggested that the solution is analyzed regularly for copper, sodium hydroxide, and formaldehyde, and adjustment made accordingly.
6. Periodic addition of 750-D and 750-C will reduce the chances of dark electroless copper deposit and should help in prolonging the life of the bath also.

Distribution:

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