Using Benchmarking to Minimize Common DOE Waste Streams

Volume IV. Sulfuric Acid Waste in Plating Shops

Prepared for
U.S. Department of Energy
Office of Waste Management
Environmental Management
Waste Minimization Division

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Abstract

Finding innovative ways to reduce waste streams generated at U.S. Department of Energy (DOE) sites by 50% by the year 2000 is a challenge for DOE's waste minimization efforts. A team composed of members from several DOE facilities used the quality tool benchmarking to improve waste minimization efforts. First the team examined sulfuric acid generation and handling processes at their sites. Then team members developed telephone and written questionnaires to help identify potential "best-in-class" industry partners willing to share information about their waste minimization techniques and technologies. The team identified two benchmarking partners, Lorin Industries, Inc., in Muskegon, Michigan, and Poly-Plating, Inc., in Chicopee, Massachusetts. Lorin Industries recovers sulfuric and phosphoric acid, cutting costs of raw materials and waste disposal. Lorin also uses a multiple-squeegee, counter-current rinse process to reduce dragout and water usage. Poly-Plating has achieved zero plating

shop waste water discharge to the city sewer system using a combination of an acid recovery system, Donnan dialysis, a cross-flow water filtration system, and electrodialysis to remove nonmetallics. Both companies have improved product quality and cut costs of raw materials and waste disposal.

ACKNOWLEDGMENTS

This report represents the efforts of many participants who shared their talents, time, and resources to further DOE's waste minimization efforts. We thank the following for their contributions:

Industry partners and their representatives:

- Lorin Industries, Inc., Dr. Joseph Manhart, Senior Scientist; Jim Nalewick, Technical Manager; Peter Laus, Project Engineer; and John Papp, Vice President for Manufacturing.
- Poly-Plating, Inc., Ed Ondrick, President; Richard Carpenter, Consultant; and Anthony D'Amato, Research Engineer.

DOE sponsors:

- Kent Hancock and Ker-Chi Chang at DOE EM-334, and Oren Critchfield at DOE/AL

DOE plating shop process experts:

- Ronald Angona, Technical Associate I, Brookhaven National Laboratory, Upton, New York
- Patrick Borello, Technical Associate II, Brookhaven National Laboratory, Upton, New York
- Michael Brooks, Electrochemical Engineer, Los Alamos National Laboratory, Los Alamos, New Mexico
- Edward Martinez, Processing Engineer, Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
- Michael McHenry, Senior Engineer, Allied Signal Aerospace, Inc., Kansas City, Missouri
- Robert Mikkola, Plating Engineer, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Y-12, Oak Ridge, Tennessee
- Chris Steffani, Metal Finishing Group Supervisor, Lawrence Livermore National Laboratory, Livermore, California

Executive Summary

Mission

Recent Executive Orders are challenging U.S. Department of Energy (DOE) facilities to prevent pollution at its source and to use recycled products. DOE continues to seek innovative ways to reduce waste streams generated at DOE sites by 50% by the year 2000.

Project Focus

Sponsored by the DOE's Waste Minimization Division (EM-334), the Benchmarking for Waste Minimization project (1) examines waste minimization techniques and technologies that have been used successfully to minimize plating shop waste, specifically sulfuric acid waste, and (2) provides this information to affected sites within DOE. Benchmarking was the methodology used for analyzing the internal processes and seeking partners that have successfully improved their waste minimization procedures.

This report describes the team findings of the best waste minimization practices for sulfuric acid in plating shops.

Benchmarking Definition

Benchmarking is the continuous process of improving products, services, and practices by identifying and understanding the current process, exchanging information with recognized leaders in the field, and implementing meaningful improvements.

Benchmarking is used by a variety of companies and organizations as a quality improvement tool. For this project, the following 12-step benchmarking process was used:

1. Identify process to be benchmarked
2. Establish management commitment
3. Identify and establish benchmarking team
4. Define and understand the process to be benchmarked
5. Identify metrics
6. Evaluate current performance
7. Identify potential benchmarking partners
8. Collect process data from potential partners
9. Analyze potential partners' data and choose partners
10. Conduct site visits
11. Communicate results
12. Continue to benchmark the process

Benchmarking Team

A benchmarking team evaluated the current internal processes used at several DOE facilities for plating shop sulfuric acid waste. The team created a process flow chart and defined process metrics. Using telephone surveys and written questionnaires, the team searched for industry partners with similar working environments that had addressed the problems that the team was investigating. The team found two benchmarking partners.

Continued on the next page...

Results

The team visited Lorin Industries, Inc. in Muskegon, Michigan, and Poly-Plating, Inc. in Chicopee, Massachusetts, to learn about their waste minimization practices.

Lorin Industries Results

Waste minimization practices at Lorin Industries include the following:

- Recovers sulfuric acid using a continuous purge process with an acid purification unit. The company avoids the cost of new sulfuric acid purchases and reduces its waste stream.
- Recovers phosphoric acid from the bright dip and electropolish line with decationizer units (DCU).
- Uses a multiple-squeegee, counter-current rinse process to reduce dragout and water usage.
- Uses reclaimed lime to perform neutralization.
- Uses a high-pressure plate and frame filter press to minimize the volume of waste sludge, saving transportation costs and landfill space.

Poly-Plating Results

Waste minimization practices at Poly-Plating include the following:

- Achieves zero discharge of plating shop waste water to the city sewer system. Using the combination of an acid recovery system, Donnan Dialysis, a cross-flow water filtration system, and electrodialysis to remove nonmetallics, the shop stopped discharging waste water in 1987.
- Recovers hydrochloric and nitric acid using acid recovery units of Poly-Plating's own design.
- Dialyzes its electroless tanks. No nickel bath has been disposed of for five years.
- Minimizes its caustic waste stream with superfiltration and scrupulous tank cleaning.

System Benefits

The partners reported the following benefits of waste minimization:

- Both companies report improved product quality because they have greater system control.
- The increasing costs of raw materials were strong drivers for both companies to increase their waste minimization effort. Both companies have reduced purchases of new acids.
- Lorin Industries was able to expand its operating lines without expanding its waste water treatment plant.
- Both companies reduced costs for water and sewer services. Lorin has reduced costs for landfill charges.

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Acronyms and Definitions

BMP	Best Management Practices
DOE	U.S. Department of Energy
ES&H	Environment, Safety and Health
H_2SO_4	Sulfuric acid
MMES	Martin Marietta Energy Systems
SNL/CA	Sandia National Laboratories, California
SNL/NM	Sandia National Laboratories, New Mexico
WMin	Waste Minimization
WWTP	Waste Water Treatment Plant

1.0 Introduction

1.1 Background

Executive Orders

Executive Orders signed by President Clinton require federal government agencies to prevent pollution and to use recycled products. Executive Order 12856 states that "It is the national policy of the United States that whenever feasible, pollution should be prevented or reduced at the source." Executive Order 12873 focuses on federal acquisition, recycling, and waste prevention and is intended "to strengthen the role of the Federal Government as an enlightened, environmentally conscious and concerned consumer."

DOE Waste Minimization Mission

The U.S. Department of Energy (DOE) has placed a high priority on waste minimization and pollution prevention, encouraging waste generators to develop programs and request adequate resources to effect long-term savings. To provide a strategy for meeting these priorities, the DOE created the Waste Minimization/Pollution Prevention Crosscut Plan (DOE, 1994). The plan states that DOE's waste minimization (WMin) mission is

> "To reduce generation and release of DOE multi-media wastes and pollutants by implementing cost-effective waste minimization and pollution prevention technologies, practices, and policies, with partners in government and industry while conducting the Department's operations in compliance with applicable environmental requirements."

DOE Objective

This benchmarking project helps to accomplish one of the major DOE Crosscut Plan Strategic Objectives which is "to identify and develop technologies and exchange information." The DOE can enhance the effectiveness of WMin efforts by exchanging applicable technologies and information with companies or organizations that are already successful in their WMin/Pollution Prevention approach. A secondary DOE objective is to work closer with U.S. industry.

Waste streams that are common in the DOE complex are logical targets for evaluation because the results can be shared across the complex.

Sponsor

The sponsor of this project is the DOE Waste Minimization Division, EM-334. The division's mission is to plan, coordinate, and develop a DOE-wide Waste Minimization and Pollution Prevention Program that results in a decrease in the amount of wastes produced by the DOE.

Benchmarking Approach

Benchmarking was chosen as the project approach because it

- has proven capabilities as a quality improvement tool,
- provides flexibility,
- may be applied to many different processes, and
- increases ties with U.S. industry.

For a complete definition of benchmarking and an explanation of the process, refer to *Using Benchmarking to Minimize Common DOE Waste Streams, Volume I, Methodology and Liquid Photographic Waste*, SAND93-3992, April 1994.

1.2 Purpose

Project Purpose

The project's purpose is to

- identify common waste streams throughout the DOE,
- provide a forum for the waste generators who produce the same waste stream at different DOE facilities,
- partner with private industry to learn the best waste minimization technologies that have been applied successfully to these waste streams, and
- provide this information to the DOE.

Benchmarking (a quality tool) provided the methodology for analyzing internal DOE site processes and for seeking industry partners that have successfully improved their own waste minimization efforts.

Report Purpose

This report describes the results of the benchmarking effort to identify the best waste minimization practices for managing the sulfuric acid waste stream.

1.3 Report Structure

This document is Volume IV in a series of waste minimization benchmarking project reports. Volume I includes the background, full project scope, benchmarking methodology, project details such as training and survey techniques, and results of the liquid photographic waste team. Volume II includes the results of the used motor oil team. Volume III includes the results of the aqueous cutting fluid team. The results of the sulfuric acid team are included in this report. Additional volumes will be added as other waste streams are studied.

Continued on the next page...

1.3 Report Structure, continued

The following table describes the report structure:

Report Section	Description
1	Project background and purpose.
2	The generic 12-step benchmarking methodology.

2.0 Benchmarking Methodology

Introduction

This section is a brief overview of the generic process of benchmarking, as defined by Sandia's Process Improvement/Benchmarking Team.

Benchmarking Definition

Benchmarking is the continuous process of improving products, services, and practices by

- identifying and understanding customer requirements and process performance,
- exchanging information with recognized leaders (internal and external to the organization),
- implementing meaningful improvements, and
- recalibrating the process by assessing the progress and monitoring trends and results.

Author Robert Camp has defined benchmarking as "the search for industry `best practices' that lead to superior performance" (Camp, 1989).

Benchmarking Steps

Figure 2-1 is a flow chart of the 12-step benchmarking methodology used at Sandia.

Figure 2-1. 12-Step Benchmarking Methodology

2.1 Defining the Benchmarking Process

Benchmarking Process

The following table shows the steps that comprise the benchmarking process. Steps 1 through 6 reflect internal process improvement. Steps 7 through 12 reflect external activities.

<table>
<tr><th>Step</th><th>Activity</th></tr>
<tr><td>1</td><td>Identify Process to be Benchmarked

The process selected must be narrow enough in scope that it is manageable. The process must be important to the work or business function and be customer-focused because a substantial amount of resources (i.e., personnel, time, and funds) are required to conduct the benchmarking study. The result must improve the process and add value.</td></tr>
<tr><td>2</td><td>Establish Management Commitment

Management is defined as the person(s) who has the authority to allocate resources (personnel, time, and funds) and who is ultimately responsible for the outcome of the benchmarking activity.

Management
• has the responsibility to make the effort to understand the fundamentals of benchmarking and to demonstrate a willingness to implement the results;
• needs to support the team and its recommendations with resources, encouragement, and commitment; and
• has the right to expect frequent updates from the benchmarking team (e.g., verbal reports, meeting minutes, reports, periodic presentations).</td></tr>
<tr><td>3</td><td>Identify and Establish Benchmarking Team

The benchmarking team members include
• process experts who have extensive knowledge of the process through their daily jobs (these are the people impacted by any changes);
• resource personnel such as facilitators, trainers, quality or benchmarking consultants, information specialists, and technical writers; and
• a project leader who guides the benchmarking process.

The team may need training in benchmarking techniques, including process definition, the benchmarking process, quality tools, questionnaire design, and interviewing techniques. The team members must understand their roles and responsibilities and commit to a common team purpose or goal. The members must attend and participate in all meetings and complete their assignments.

Continued on the next page...</td></tr>
</table>

Step	Activity
4	**Define and Understand the Process to be Benchmarked** The team defines the process through an understanding of important process elements: inputs, outputs, suppliers, and customers. The customer drives the business, and therefore, the team needs to understand the customers' wants, needs, and expectations. The team's final output for this step includes a process flow chart depicting the work flow and the relationships between people and organizations. The output from this step lays the foundation for the remainder of the benchmarking activity.
5	**Identify Metrics** The metrics must be meaningful to the process. Example metrics include customer requirements, cost, cycle time, and quality. Metrics, when possible, should be consistent with established standards (i.e., industrial, national, international). The process metrics aid in evaluating and assessing the current process. Strength and weakness trends developed from the metrics can identify areas for improvement and provide guidance and direction for selecting improvements to be implemented. Effective metrics provide guidance for developing survey tools for benchmarking partners.
6	**Evaluate Current Performance** The metrics help to identify the process areas to be improved and the nature of the improvements. The team may need to develop a decision matrix for ranking the improvements. A cost/benefit or return-on-investment analysis may be required to evaluate whether the benchmarking process should be continued. If the recommendation for implementation of the appropriate process improvements is made, it is necessary to monitor the trends and results. Benchmarking does not automatically assume that outside partners are required.
7	**Identify Potential Benchmarking Partners** Based on the metrics collected from the internal process, the team needs to identify and establish criteria for "best in class" partner selection criteria. The team can identify potential partners through numerous resources: database searches and contacts with external organizations, knowledgeable individuals, suppliers, and customers. The team needs to identify a sufficient pool of partners to determine the few they will visit. Partners that have better processes are not always easily found. A team may discover that their own processes are better than those of the potential partners. *Continued on the next page...*

Step	Activity
8	**Collect Process Data from Potential Partners** The team develops surveys to obtain preliminary information from potential partners. Surveys may consist of questionnaires, telephone interviews, or face-to-face interviews. (Normally, site interviews are reserved for Step 10.) The survey questions are based on the process metrics and criteria established for selecting partners. Up-front planning on how to analyze the quantitative and qualitative data is essential for developing good surveys.
9	**Analyze Data and Choose Partners** The preliminary data are used to select partners for site visits and interviews. The project leader compares the data gathered from the potential partners to the metrics and criteria set by the team. The final partner(s) must have a process that is applicable (in this study) to various DOE sites. The project leader should make direct comparisons of the data, process parameters, and constraints. The team analyzes the data and determines weighting and ranking criteria in order to select the final partners. If the team cannot find a partner that can provide substantial process improvements, the team needs to rethink the project. The team may decide • to repeat several steps, which includes revising the criteria, expanding the pool of potential partners, collecting new process data, and re-analyzing the data in the search to find appropriate partners; or • to conduct an internal evaluation; or • to terminate the benchmarking effort.
10	**Conduct Site Visits and Reanalyze Data** To gain the maximum benefit from partner site visits, careful and thorough preparation is essential. Preparation includes, but is not limited to, determining appropriate interviewees, assigning team interviewing roles, developing a list of questions and a meeting agenda, and determining how to handle the interview data. The site visit is an opportunity for two-way communication between the benchmarking team and each partner. During the site visit, the team conducts an in-depth interview. It is essential that the team develop an effective interview guide for each partner before the site visit. After all partners' information is collected, the quantitative and qualitative data are analyzed. A decision matrix may be used to identify and select the partners' practices to be incorporated.

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Step	Activity
11	**Communicate Results** The team reports results to upper management and all involved parties and develops an action plan that describes the team's recommendations, methods for implementation, and implementation costs and schedule. The findings need to be adaptable to the process and the organization's culture and constraints. The improvements need to be monitored and evaluated.
12	**Continue to Conduct Benchmarking of Process** The best process today may not be the best process tomorrow. Depending on the amount of change in the process, customer requirements, competition, technological advances, and changing business practices, it is important to revisit the process, or specific aspects of the process, periodically.

Reference

This section is an adaptation of Section 2 of the report, *Benchmarking the Property Inventory Process at Sandia National Laboratories*, SAND92-2565 (Ramirez and Hill, 1993). It describes the generic process of benchmarking, as defined by Sandia's Process Improvement/Benchmarking Department.

Benchmarking Details

For details on the benchmarking methodology used for this project, refer to *Volume I, Methodology and Liquid Photographic Waste*, SAND93-3992, April 1994. For a copy of Volume I, contact the author at (505) 844-8956 or through the Environmentally Conscious Life Cycle Systems Department, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

3.0 Sulfuric Acid Waste Benchmarking Results

Adaptation of Benchmarking Methodology

The 12 steps of the benchmarking methodology listed in Section 2 provide the framework for this project.

Benchmarking is a flexible process that lets each team adapt the standard procedure to the unique needs of the project.

The following chapter describes how the sulfuric acid team used the benchmarking process to collect information on Best Management Practices and other techniques and technologies for minimizing sulfuric acid waste within DOE.

3.1 Step 1: Identify Process to be Benchmarked

DOE's Waste-Generating Activities

Figure 3-1 illustrates four major types of waste-generating activities within the DOE, including:

- mission-related,
- waste management,
- environmental remediation, and
- infrastructure-related.

Infrastructure-related activities are the DOE's "landlord" activities as shown in the lower portion of Figure 3-1. Infrastructure-related activities were chosen because they have not yet received the same DOE-wide attention that the other three waste-generating activities have received. These activities produce DOE-wide waste streams that are also produced in outside industry. Therefore, they are ideal activities for benchmarking because appropriate industry partners should be easy to identify and locate.

Figure 3-1. Waste-Generating Activities in DOE

Identification of Common Waste Streams

Initial activities centered on collecting information on as many DOE waste streams as possible. Refer to Volume I for the detailed rationale for selecting plating shop waste as one of the waste streams for benchmarking.

Plating shop waste was chosen for benchmarking because it is a common concern throughout the DOE. Advances in waste minimization techniques and technology made by the U.S. plating industry are available to the DOE through benchmarking partnerships.

☞ **OUTCOME OF BENCHMARKING STEP 1:**
Process chosen for benchmarking:
- **Plating shop waste**

3.2 Step 2: Establish Management Commitment

Strong DOE Commitment

Because of DOE's emphasis on waste minimization, management commitment was a positive element in this project. The DOE sponsor for this project is the Waste Minimization Division, EM-334. Management support included the following:

- Headquarters provided project funding and guidance.
- The Albuquerque Field Office provided support through the WMin coordinator.
- Site management allowed the process experts the time to participate.
- Sandia management provided benchmarking expertise and trainers.

> ☞ **OUTCOME OF BENCHMARKING STEP 2:**
> **DOE management committed resources at national, regional, and local levels.**

3.3 Step 3: Identify and Establish Benchmarking Team

Team Members

A benchmarking team usually consists of a project leader, process experts, management, and support personnel. Not all team members are required to participate at all times. Some team members may perform more than one role, as needed, for the team at large and for smaller subteams.

Finding Team Members

The project leader used the following sources to find benchmarking team members:

- Contacts within the DOE
- Proceedings from waste minimization conferences
- Discussions with site waste minimization coordinators

Roles and Responsibilities

The following table outlines suggested roles and responsibilities needed for a benchmarking effort.

Role	Responsibilities
Project Leader	Plan, organize, assign tasks, and oversee the benchmarking project.
Process Experts	Provide professional expertise on the target process during the workshops, contact industry partners, and conduct site interviews.
DOE Management	Set policy and provide support, personnel, time, and funding.
Trainers/Facilitators	Teach participants benchmarking techniques and lead workshops and work sessions to accomplish goals.
Information Specialist	Aid the search for potential benchmarking partners through database searches.
Writer/Recorder	Document the benchmarking process by recording workshop activities and provide support for project leader, as needed.

Continued on the next page...

Team Roster

The following table lists the plating shop team members:

Team Member	Title	Location
Ronald Angona	Technical Associate I	Brookhaven National Laboratory, Upton, New York
Pat Borello	Technical Associate II	Brookhaven National Laboratory, Upton, New York
Michael Brooks	Electrochemical Engineer	Los Alamos National Laboratory, Los Alamos, New Mexico
Diane Leek	Technical Writer	Tech Reps, Inc.
Victoria Levin	Project Leader, Environmentally Conscious Life Cycles Systems	Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
Edward Martinez	Process Engineer	Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
Michael McHenry	Senior Engineer	Allied Signal Aerospace, Inc., Kansas City, Missouri
Robert Mikkola	Plating Engineer	Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Y-12, Oak Ridge, Tennessee

☞ **OUTCOME OF BENCHMARKING STEP 3:**
Planning team, benchmarking team, and interview team successfully assembled.

3.4 Step 4: Define and Understand the Process to be Benchmarked

Process Foundation

Step 4 lays the foundation for all future activity. The team must define and understand the existing process before examining another's process. This step establishes the baseline from which to measure performance gaps.

Workshop Activities and Goals

The project leader, process experts, and support staff attended a workshop that provided training and a work session for the entire team, covering several benchmarking steps.

The goals of the first workshop were to

- Define and understand the process to be benchmarked (Step 4),
- Create a flow chart of the generic process (Step 4),
- Define the metrics of the process (Step 5), and
- Define the criteria for choosing potential partners (Step 7).

The table below summarizes the workshop activities. A detailed description of the activities follows the table.

Stage	Activity
1	Workshop facilitator directed team-building exercises to integrate the team into a cooperative, working unit.
2	Workshop facilitator trained the team in the benchmarking methodology so that team members understood the group process, the task, the commitment, and the work involved to complete the project.

Stage 1 — Team Building

Team Building

The team-building exercise resulted in a team name, motto, logo (see Figure 3-2), and mission statement.

Team Name	**The Minimizers**
Motto	**Close the Loop**

Figure 3-2 Logo for the Minimizers

Stage 2 — Train the Process Experts

The process experts were chosen for their knowledge of their fields and the tasks they perform in their daily jobs. However, they needed training in the benchmarking process.

Stage 3 — Create a Consensus Flow Chart

Process Flow Chart

The process experts came from a variety of sites that had different procedures, products, and customers. However, acid waste management was a common problem for all sites. The team needed to create a flow chart that expressed the process "big picture." The facilitator helped the group define the process parameters.

Process Parameters

All processes have the following common parameters:

- Inputs
- Suppliers
- Outputs
- Customers

The team used the parameters above to help them define the particular process that produces the sulfuric acid waste stream. For each parameter, the team listed ideas, and then evaluated each component to confirm that it was directly related to the sulfuric acid waste stream. The final lists are shown below.

Inputs

Inputs for the sulfuric acid waste stream include:

- fresh sulfuric acid (H_2SO_4)
- filter cartridges
- energy (electricity)
- tanks--equipment
- part to be worked on
- anode/cathode material
- water
- labor
- make-up air
- other chemicals
- drag in from other processes
- miscellaneous contaminants (airborne, other)
- chemical analysis

Suppliers

Suppliers for the sulfuric acid waste stream include:

- chemical companies
- stockers
- operators
- utility companies
- laboratory technician for analysis
- part customer
- ambient environment
- container and equipment supplier
- other chemical processes

Customers

Customers of the sulfuric acid waste stream include:

- waste treatment facility
- part customer
- waste customer
- employee/labor
- ES&H organization, management, regulators (EPA, DOE)
- storage facility

Outputs

Outputs of the sulfuric acid waste stream include:

- contaminated sulfuric acid
- parts
- dirty tanks
- rinse waters
- dirty filter cartridges
- empty containers
- fumes/air emissions
- documentation
- waste containers
- need for waste treatment, storage, disposal
- expired chemicals

Flow Chart

After the lists were finalized, the team created a flow chart (Figure 3-3) that diagrams the waste sulfuric acid generation and handling process.

☞ **OUTCOME OF BENCHMARKING STEP 4:**

Waste sulfuric acid process inputs, outputs, customers, and suppliers were identified. A flow chart of the generic process was completed.

Figure 3-3. Waste Sulfuric Acid Generation and Handling Process

3.5 Step 5: Identify Metrics

Definition

Metrics are the measures of the internal process. Metrics allow evaluation and assessment of existing performance and provide points of contrast after the lessons learned from the benchmarking activity have been applied.

Metrics

After the process flow chart was created (see Step 4), the facilitator led the team through a discussion of the metrics.

The group decided that the following metrics were relevant:

- pounds (lb) of sulfuric acid per part new
- lb of sulfuric acid per part waste
- maximum contamination levels for usable bath (that determine whether a bath is bad)
- operating concentration, temperature of H_2SO_4 bath
- production rate lb/month or sq ft/month
- total volume of H_2SO_4 waste generated
- number of dumps/month/year
- average bath capacity
- operating volume of the tank
- volume of new sulfuric acid used per year
- frequency of analysis
- number of employees
- type of bath (pickling, stripping, etc.)
- bath capacity
- tank size
- cost of treatment, storage, disposal
- cost of recycling equipment
- total volume of sulfuric acid waste and metal

NOTE: Not all the metrics are easily obtainable within DOE.

☞ **OUTCOME OF BENCHMARKING STEP 5:**
The team defined waste sulfuric acid process metrics that will provide the measures of the internal process.

3.6 Step 6: Evaluate Current Performance

Information Exchange

The team performed an informal evaluation of each site's performance by exchanging information and comparing activities and processes. Each process expert had the opportunity to discuss and explain site processes during the first workshop. A summary of sulfuric acid use at the participating DOE plating shops is shown in Table 3.1.

Plating Shop Site Visit

One of the team meetings was held at Lawrence Livermore National Laboratory (LLNL), enabling team members to see the waste minimization efforts at that plating shop. At LLNL, the waste minimization efforts fall under three main categories:

- Substitution
- Segregation
- Minimization/recycling

Substitution

LLNL's substitution waste minimization efforts are listed below:

- Replaced a cyanide-based copper strike with a pyrophosphate copper strike to retain the use of a copper strike in the main shop
- Replaced a sulfuric acid anodizing system with an oxalic acid hard anodizing system
- Replaced a nitric hydrofluoric acid desmut with a ferrous sulfate deoxidizing bath
- Switched to a non-cyanide chemical conversion coating
- Switched to a pressure washer instead of a vapor degreaser and got rid of an organic solvent
- Replaced a hexavalent chromium deposit with a tertiary nickel tungsten boron deposit

Segregation

LLNL's segregation waste minimization efforts are listed below:

- Moved all cyanide-related processes to a cyanide room. Removed cyanide from all other waste streams, reducing cost of handling.
- Segregated work by metal lines. LLNL has a separate line for copper, nickel, and anodizing. Unfortunately, LLNL is not able to extract metals for recycling because electrowinning is considered a treatment method in California and the laboratory is not authorized to perform treatment.

Minimization/ Recycling

LLNL's current minimization/recycling waste minimization efforts are listed below:

- Remove free oil with a membrane filtration system, which cuts LLNL's alkaline detergent waste stream from 400 gallons (gal) to 5 gal of effluent annually.
- Recycle sulfuric acid with dialysis membrane system.

Continued on the next page...

Minimization/ Recycling, continued

LLNL's current minimization/recycling waste minimization efforts are listed below: (continued)

- Minimize electricity use. In the past, all of the heaters, exhaust fans and equipment ran all the time. As part of an energy conservation program, shop personnel turn off the heaters and all equipment at night. A computer system automatically turns on the equipment at 6 a.m., before the workers arrive. The computer system saves $60,000 a year in electrical costs.
- Minimize water use by using a three-step washing process. (See Dragout/Rinse Tanks below.)
- Electroless nickel solution membrane system allows unlimited metal turnovers without disposal.
- Minimize spills with in-tank filters and pumps that keep all equipment over the tank. All filtration equipment for removal of airborne particulate matter is right in the tank.
- Use ultrasonic machines (combined with a detergent solution) that scrubs parts better than manual cleaning and produces less waste.

Dragout/Rinse Water

The dragout/rinse water waste minimization efforts are listed below:

- LLNL uses a spray and dip rinse process:
  - Use a spray rinse that rinses the chemical back into the tank (heat evaporates extra water)
  - Use a spray rinse into a dragout rinse tank.
  - Use an immersion rinse in static rinse tank. (Conductivity is maintained by automatic methods.)
  - Use a hot deionization rinse for the final rinse (maintained automatically).
- LLNL uses a cold vaporization process for rinse water recycling.
- The deionized water system uses a mixed bed resin and has carbon filters to remove organics and ultraviolet lamps to kill bacteria.

☞ **OUTCOME OF BENCHMARKING STEP 6:**

- **Individual team members shared information on each site's process and established network contacts for future problem solving.**

3.7 Step 7: Identify Potential Benchmarking Partners

Search Parameters

"Criteria" are defined as standards on which a judgment or decision may be based (Webster's, 1985). The team developed criteria to be used to identify appropriate potential partners. Defining criteria limited the search to partners that fit the team's needs.

Criteria

The plating shop team defined the following criteria for potential partners. A potential partner must:

- **generate H_2SO_4 waste.**
- **have common operations with DOE (pickling, etchback, etc.)**
- **use at least 500 gal of H_2SO_4 per year.**
- **know how much H_2SO_4 is used in a year and how much H_2SO_4 waste is produced in a year (mass balance).**
- **recycle H_2SO_4 or minimize it.**
- **have a minimum 25-gal tank size.**
- **have a 100-gal total capacity with at least 2 turnovers per year**
- **have deionization capability.**
- **have a waste minimization program.**

Information Sources for Identifying Potential Partners

A variety of methods and sources for identifying potential partners, including the following, were used:

- Literature search by an information specialist
- Process experts' suggestions
- Contacts through customers or suppliers
- Trade associations or publications

> ☞ **OUTCOME OF BENCHMARKING STEP 7:**
> **A list of 54 potential partners was identified.**

3.8 Step 8: Collect Process Data from Potential Partners

Data Collection Methods

In benchmarking, the main tool for gathering initial process data from potential partners is a questionnaire, either oral or written. Both types were used for this project.

Questionnaire Development Training

The benchmarking team learned questionnaire development techniques and how to define the questions to pose to potential partners.

Refer to Volume I, Appendix B, for an abbreviated training guide on questionnaire development techniques. Refer to Appendix A in this volume for the final telephone and written questionnaires used in this project.

Questionnaire Development Process

The group discussed what information would help them find benchmarking partners. The group needed two questionnaires:

- a telephone questionnaire to act as a filter to determine industry partner interest and broad suitability, and
- a written questionnaire that would elicit detailed information to help determine the final candidates for site visits.

Results

Of the 54 initial contacts made by the sulfuric acid team by telephone, 3 of the companies

- had processes that were appropriate for comparison to the DOE's process defined by the process experts, and
- were willing to participate.

Written questionnaires were sent to these companies. Of the 3 written questionnaires sent, 3 were returned. (This return rate of 100% exceeds the average return rate of 30-60% for prescreened written questionnaires.)

Problems Encountered

One of the difficulties of this project was finding appropriate partners. Most of the potential partners contacted were not minimizing sulfuric acid waste because the acid waste stream was used to balance the caustic waste stream for waste disposal purposes.

> ☞ **OUTCOME OF BENCHMARKING STEP 8:**
> **The team conducted 54 telephone questionnaires. Three written questionnaires were sent to potential partners.**

3.9 Step 9: Analyze Potential Partners' Data and Choose Partners

Choosing Benchmarking Partners

To choose final partners, the questionnaires were evaluated to determine if respondents:

- Showed a major decrease in disposal volume after implementation of new process
- Had ideas or technology that provided new information
- Had extended the life of sulfuric acid baths

☞ **OUTCOME OF BENCHMARKING STEP 9:**
The benchmarking partners chosen for the sulfuric acid waste stream were:

- **Lorin Industries, Inc. in Muskegon, Michigan**
- **Poly-Plating, Inc. in Chicopee, Massachusetts**
- **Valley Plating, Inc. in Los Angeles, California**

3.10 Step 10: Conduct Site Visits

Team Visits Partners

The interview team, a subset of the benchmarking team, received training on interview techniques, rules of conduct, and agenda development skills. The interview team visited Lorin Industries in Muskegon, Michigan, and Poly-Plating in Chicopee, Massachusetts, to gather information on best management practices and processing techniques for sulfuric acid. The project leader visited Valley Plating, Inc., in Los Angeles, California.

- For an abbreviated training guide on on-site interviewing techniques, refer to Volume I, Appendix D.
- For the plating shop team's final interview question set, refer to Appendix B of this document.

3.10.1 Lorin Industries, Inc. Site Visit

Company Introduction

Lorin Industries, Inc. of Muskegon, Michigan, is the world's largest volume coil anodizer of aluminum. Anodizing, an electrolytic process using sulfuric acid, converts the surface of the aluminum to a porous aluminum oxide, which may be colored using dyes or by plating metals into the pores. The finished coils are used by other manufacturers to produce lighting sheet for parabolic reflectors; spacer bar used between the panes of thermopane windows; shutters for diskettes, and architectural, electronic, and miscellaneous items.

Production Lines

Six production lines operate continuously as coils of aluminum unwind at the starting point, pass through various treating stations, and rewind as finished coils. Production lines run 24 hours a day, seven days a week. As a coil unwinds, the continuous sheet of aluminum is subjected to a series of baths and rinses. At the end of the production line, the coil is rewound, inspected for quality, and shipped.

Sulfuric Acid Recycling

The sulfuric acid concentration of 26% is maintained in the anodizing tank. The anodizing tank provides a continuous purge, with the overflow moving into a purge tank. From this tank, the solution is pumped to the acid purification unit (APU) for recycling. The APU holds sulfate on resin, allowing aluminum ions to pass through to waste. A water cycle recovers the sulfuric acid. The recycled acid flows to a holding tank, and then it is added back into the anodizing tank as fresh acid is needed. Figure 3-4 depicts the recycling process.

Figure 3-4 Lorin Industries' Sulfuric Acid Recycling Process

Lorin uses continuous addition of recycled sulfuric acid to maintain the aluminum at a level close to 3 to 6 grams per liter. Titration with sodium hydroxide (NaOH) indicates when manual additions are required to maintain the concentration of sulfuric acid. If the purge was not performed, the aluminum concentration would build up and the acid concentration would drop. Metallic ions other than aluminum are removed along with the aluminum in the recovery unit.

3.10.1 Lorin Industries Site Visit, continued

Sulfuric Acid Recycling, continued

The purge rate is increased or decreased based on the results of chemical analysis, which is performed every eight hours. Autotitration is used for the acid analysis and atomic absorption is used for checking the aluminum concentration. Lorin has an in-house laboratory with full-time analysts.

The byproducts of the APU system are recovered sulfuric acid and a waste stream containing aluminum and sulfuric acid.

Rinse Waters

To reduce dragout, Lorin uses a multiple-squeegee, counter-current rinse (MSCCR) system that provides rinsing while minimizing water usage. As the continuous aluminum web moves up toward the next process tank, it passes through several sets of squeegee rolls. Water is sprayed only below the top squeegee. Water runs down the sheet and over the squeegee below and back onto the web. Each squeegee prevents most of the rinse water from traveling up the web. Spray is pumped onto the incoming sheet from the bottom of the tank. Water runs down over the three sections of the MSCCR. A deep well (immersion) rinse in the next tank is the source of rinse water to the MSCCR. City water is sprayed onto the outgoing sheet.

However, sulfuric acid is not recovered from rinse waters. Currently, the concentration of sulfuric acid in rinse water is so low and the cost of rinse water disposal is so low that Lorin is not ready to purchase the equipment and dedicate labor to run and maintain this type of system.

Sulfuric Acid Loss

Not all sulfuric acid is recaptured for anodizing. Sulfuric acid **loss** occurs through:

- adhering to the aluminum coil
- APU waste
- rinse waters

Disposal of Waste

Rinse water from the sulfuric acid processes is sent to the on-site waste water treatment plant (WWTP). The WWTP performs a pH adjustment with lime, then flocculates, clarifies, and filters the waste water before releasing it to the sewer for treatment in the Muskegon County waste water management system.

All plant liquid wastes (largely acidic) are combined in the wastewater system and neutralized using lime. Lorin acquires lime that was generated as a byproduct of a previous acetylene manufacturer. The Michigan Department of Natural Resources (DNR) had been seeking a method to remove the lime, a cast-off from an old manufacturing process. This need led to a cooperative effort. Several area companies are using this low-cost resource.

3.10.1 Lorin Industries Site Visit, continued

Production Quality

Production quality has improved since the introduction of the purge bath by maintaining a lower and more constant aluminum content in the anodizing solution.

Worker Involvement

There are two main jobs on the production lines:

- processors who handle the coils and keep the web moving and
- control men who handle the chemical balances and baths.

In the past, a worker was assigned one role and performed that role only. Two years ago, Lorin changed the way management assigned work. Now, a shift team has the responsibility for doing the job. The team decides how to divide the work. Workers are cross-trained and may switch roles from day to day. Lorin does not have a union. Promotions from hourly to salary status often come from within.

Quality control inspectors and waste handlers are separate teams from production workers. Waste handlers run the neutralization clarification system and the acid recovery systems and handle chemical receipts and sludge removal.

Drivers for Waste Minimization Policy

The drivers for Lorin's waste minimization policy were:

- Reduce costs of the manufacturing process by buying less raw materials, in this case sulfuric acid and phosphoric acid.
- Reduce disposal costs by reducing volume of waste going to a landfill.
- Reduce costs of water and sewer charges.
- Expand the number of operating lines without increasing the load on the on-site WWTP. Lorin wanted to expand its manufacturing capabilities, but the clarifier already was operating at capacity. The company did not want to spend additional money to expand its WWTP.

3.10.1 Lorin Industries Site Visit, continued

Waste Minimization Success Summary

Lorin Industries' efforts in waste minimization have focused on:

- Sulfuric acid recycling
- Phosphoric acid recycling
- Using reclaimed lime to perform neutralization
- Using a multiple-squeegee, counter-current rinse system to minimize water usage
- Using high pressure plate and frame filter presses to minimize volume of waste sludge. The press enables longer cycles to increase solids content of sludge from about 25 to 40%, reducing the volume for disposal.

The following describe Lorin's successes in the waste minimization of acid waste streams:

- **Recovers sulfuric acid** using a continuous purge process with an acid purification unit manufactured by Ecotech of Pickering, Ontario, Canada. The APU handles 600 gal per hour. The company estimates that it recycles 14 million pounds of sulfuric acid solution every year, saving approximately $252,000 per year in avoided costs for buying new sulfuric acid. Also, Lorin made technical changes to the APU to optimize the cycle volumes for Lorin's concentrations of acids. Lorin also installed longer-lasting valves, pumps, and filters. With the addition of two new production lines, Lorin has purchased another APU for anodizing sulfuric acid recovery.
- **Recovers phosphoric acid** from the bright dip process and electropolish line with decationizer units (DCU) also manufactured by Ecotech. Lorin's internal volume was so low that it now buys waste phosphoric acid rinse water from another company's bright dip process and uses this rinse water, further reducing costs compared to buying new phosphoric acid. The Michigan Department of Natural Resources helped Lorin incorporate the waste rinse water into the process.
- **Uses reclaimed lime**, rather than the traditional sodium hydroxide (NaOH) for neutralization of sulfuric acid waste from rinse waters. The reclaimed lime is less expensive than NaOH. However, it is a slurry that requires longer contact time with the acidic waste than NaOH requires. Because the total waste stream at Lorin tends to be more acid than caustic, Lorin does not use sulfuric acid to balance the waste stream, as some anodizers do.
- **Uses a multiple-squeegee, counter-current rinse** concept to reduce water usage. See previous Rinse Waters section.

3.10.1 Lorin Industries Site Visit, continued

Future Plans

As time and funds become available, Lorin plans to implement the following:

- A system to capture a first rinse that is concentrated enough to recover sulfuric acid using ion exchange and evaporation.
- Any rinse tank using incoming and outgoing fresh water sprays should be modified to catch the runoff from the outgoing sprays and pump it to incoming sprays, which would result in half of the water usage per rinse station.
- Improve squeegee effectiveness by 1) assuring a tight wrap of the sheet to the squeegee, 2) using the proper squeegee hardness to most effectively remove the solution, and 3) finding a way to use offset squeegees instead of "on the exit roll" squeegees in more process tanks.
- Implement a caustic recovery system that would recycle sodium hydroxide and make a salable aluminum hydroxide.
- Instead of disposing of the phosphate-containing sludge from the combined wastewater treatment system, sell the sludge as fertilizer. Work is currently underway with Michigan Tech and Michigan State to develop this concept.
- Hire a full-time environmental manager to concentrate on waste minimization.
- Possible manufacture of alum from the APU waste stream and aluminum hydroxide from the caustic recovery system.

Enablers

The following factors contributed to the implementation of waste minimization best practices at Lorin:

- The company owner supports waste minimization efforts when the cost is justified.
- Management is responsive to suggestions.
- The company encourages a team approach to completing work. Workers are cross-trained and can perform different jobs as needed. The maintenance workers can perform welding, pipe fitting, and a variety of tasks, rather than requiring a special job category.
- The Michigan Department of Natural Resources, the state regulators, provides assistance.
- Focusing on one product enables the squeegee and counter-current rinse process.

3.10.1 Lorin Industries Site Visit, concluded

Disenablers

The following factors were identified by Lorin Industry representatives as disenablers they have encountered in their waste minimization efforts:

- The low cost of water and sewer services does not encourage water use reduction or minimizing discharge to the sewer.
  - Water is cheap and plentiful in Muskegon.
  - The cost of sewer disposal is approximately $.03/gal. It is hard to justify the cost of a rinse water reuse system when disposal is so cheap.

- More time is needed to engineer and implement change.

- Operators and lower management are resistant to change: "We've always done it this way" mentality.

- The risk of clogging spray rinses and reducing productivity is not worth the effort to reuse rinse waters because of the high calcium content of the water. Aluminum hydroxide, a byproduct of anodizing, is hard to clarify. It could clog spray nozzles in the cascade. A filtering device might allow Lorin to reuse water for some rinses, but is not currently planned.

- Shutting down a production line to make a machine modification is a major ordeal but it is necessary to implement change. Better coordination is needed between engineering, purchasing, operators, and maintenance to make the most effective change.

- Upper level management support for waste minimization is strong, but sometimes priorities get in the way. Business decisions have to be made, such as, "Should we put in Line 8 or a caustic recovery system?"

3.10.2 Poly-Plating, Inc., Site Visit

Company Introduction

Poly-Plating, Inc., of Chicopee, Massachusetts, is a plating shop that employs 16 employees in the production of nickel-plated parts. The company stopped discharging liquid waste from the plating shop to the city sewer system on Sept. 12, 1987. The system enabling closed loop operation was designed and developed by the company owner and employees. Incoming city water usage has been reduced to 880 gal a day, down from 78,000 gal per day.

Production Lines

The shop has three electroplating lines and an on-site laboratory that performs all necessary chemical analyses. A chemist performs a daily analysis for rinse water quality, including iron, copper, and nickel content. Oven calibration is the only technical service provided by an outside source. All plating processing tanks have in-tank filtration units. Rinse tanks have hand-nozzle spray rinses.

Zero Wastewater Discharge

In response to ever-stricter requirements imposed by the city of Chicopee, Poly-Plating began seeking zero discharge technology in 1983. Dissatisfied with the technology that was on the market at that time, Poly-Plating began designing and building their own equipment. The result is a zero waste water discharge system that has the following basic components:

- **Acid recovery system** that uses ion-exchange membranes arranged in a stack for diffusion dialysis. As the acid solution moves through the stack, acid molecules migrate through the membrane. Two end products result: a recovered acid solution that is 90% of the original strength, and a depleted solution containing the contaminant metal (in this case, nickel). The recovered acid is returned to the production line. Poly-Plating evaporates the depleted solution to increase the concentration and runs the solution through the recovery system a second time.

- **Donnan dialysis** that removes nickel from the rinse water using ion-exchange membranes. (This unit can target specific cations or anions for removal and concentration.) It is an alternative to conventional ion-exchange technologies with the added advantage of continuous usage, with no regeneration downtime. The Donnan dialysis unit performs: (1) deionization of closed-loop process water, (2) recovery of metal salts from low concentrations (less than 1 part per million (ppm)), and (3) nonadditive pH adjustment.

- **Cross-flow filtration system** uses a membrane filtration process that separates suspended solids from waste water.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Zero Wastewater Discharge, continued

Components of the zero waste water discharge system (continued):

- **Electrodialysis** that removes the nonmetallics present in the rinse water, such as sodium, potassium, sulfates, and chlorides. The unit performs ion exchange utilizing alternating sequences of cation membranes and anion membranes to separate and concentrate dissolved salts out of the rinse water.

- **Electroless nickel dialysis recovery system** that selectively removes bath impurities that build up during normal operation, allowing the bath to be used indefinitely.

Closed Loop System

A constantly moving cycle of 28,000 gal of water moves from the rinse tanks through a series of pits in a closed-loop system. The contaminated rinse water moves through a series of four pits:

- Pit #1 receives all contaminated rinses and aerates and breaks down all organics.
- Pit #2 uses a Donnan dialysis unit to remove nickel.
- Pit #3 adjusts the pH and chlorinates the water, as needed.
- Pit #4 uses an electrodialysis unit to remove nonmetallic anions and cations (nonmetals such as sodium, potassium, sulfates, and chlorides). Purified water returns to the rinse tanks. This step also performs a final pH adjustment (balanced to pH 6.2).

A shop layout showing the integration of the acid recovery units, the rinse water pit system, and the plating lines is shown in Figure 3-5. The shop design incorporates a gently sloping floor underneath the plating processing tanks. One pump is needed to recirculate all water.

Acid Recycling

An acid recovery system serves each one of the three electroplating lines. For lines using hydrochloric acid, the recovery system is placed at the acid activation point. For the nickel plating line, the acid recovery unit is linked to the nitric acid tank that is used for overnight passivation of the electroless nickel tank.

System Capacity

The system was designed to run unattended and to accommodate three days of recovered materials so no one would need to come in over the weekend or on holidays. The system had its most stringent test one Saturday when a worker started a task, left a water hose running in a tank, and answered the telephone before the task was finished. He left the building, forgetting the running water. When the crew opened the shop Monday morning, the tank had flooded and water was running down the sloped floor into the pits. The system processed all runoff; no water left the shop; and no permanent or costly damage resulted from the mistake.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Applications

Poly-Plating uses the acid recovery system for recovering:

- hydrochloric acid from stainless steel and titanium pickling, and metal cleaning baths and cation exchange regenerant solutions.
- nitric acid from rack stripping, rework stripping, and tank passivation.

However, the processes described have applications for all mineral acids commonly found in plating shops, for example:

- sulfuric acid from aluminum anodizing, steel pickling, or metal etching.
- phosphoric acid from electroplating and bright dipping.

Production Quality

Production quality has improved since the system was installed. In the winter, city water feeds into the building at 38°F. Ambient rinse water in Poly-Plating's recycled rinse water system is 60°F. Every six months, the City of Chicopee adds chlorine to the water, which introduces rust into the shop. Now, because of the low volume of added city water, constant temperatures are maintained, the small amount of rust is filtered with a cartridge filter, and the shop avoids seasonal problems presented by city water.

Worker Involvement

Four workers are certified to use and maintain the equipment. The equipment does not require a high level of technical expertise to operate or maintain. Systems are operated by production personnel.

Disposal of Waste

The system waste products are described below:

- Liquid nickel salts, the byproduct of the electrodialysis unit and the Donnan dialysis unit, are disposed of as uncontrolled nonhazardous materials. (1000 gal per year)
- Liquid effluent from the acid recovery system is stored in 55-gal drums on site. Poly-Plating plans to use it for experimenting with more selective membranes. Other users of the system may perform waste treatment on site, recover metals, or neutralize and filter the liquid, which could be disposed of as a nonhazardous waste.
- All system filters are disposed of as hazardous waste, as well as gloves or materials used for spill clean-up.
- An alkaline proprietary strip is disposed of as non-hazardous waste (370 gal per year.)

System Benefits

The benefits of the system are:

- New acid purchases were cut 99% from 1989 levels. For example, in 1989, Poly-Plating bought 100,000 lb of nitric acid. In 1994, the company bought two 55-gal drums of nitric acid, approximately 800 lb.

Continued on the next page...

3.10.2 Poly-Plating, Inc., Site Visit, continued

System Benefits, continued

The benefits of the system are: (continued)

- Poly-Plating avoids escalating city water and sewer charges, permits, testing charges, etc. The company estimates an avoided cost of $75,000 per year from the water charges alone.

- The reject rate has dropped significantly since the new technology was implemented.

- Poly-Plating is classified as a Level 1 Vendor. The company receives an increased amount of work because it is a zero wastewater discharge shop. Customers have less potential liability.

- The system is over-engineered for the volume of work in the shop. The cross-flow filters are used only when Poly-Plating has a spill. Initially, when city water was used, the cross-flow filters were used to clean the incoming water from the city system. Now, a small 10-inch cartridge is used to filter the city water used to make up for the loss from evaporation. At 1 ppm of nickel, the Donnan unit is shut off. The unit is restarted when the nickel content reaches 10 ppm.

- A second company, Zero Discharge Technologies, resulted from the system development.

Drivers for Waste Minimization Policy

The drivers for Poly-Plating's waste minimization policy were:

- **Requirements from federal, state, and city sources.** State regulations were tighter than federal regulations, and city regulations were more rigorous than state regulations. As time goes on, Poly-Plating expects these regulations to become more stringent. For example, the allowable level for nickel in discharge waters is 2.54 parts per million (ppm) in the Chicopee area, and 1.0 ppm in the Boston area.

- **Dissatisfaction with the inflexibility of the bureaucracy.** The company president was strongly motivated by the desire to be free of officials. For example, the city was charging Poly-Plating $8,500 per year to duplicate testing that Poly-Plating was already required to perform. Poly-Plating eliminated that cost when it achieved zero sewer discharge.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Drivers for Waste Minimization Policy, continued

The drivers for Poly-Plating's waste minimization policy were (continued):

- **Increasing costs of public utilities.** In 1983, when the company began to look for alternative solutions, incoming city water was $.20 per 100 ft^3 with no additional charge for sewer discharge. In 1995, incoming city water is $1.20 per 100 ft^3 and sewer discharge fees are $1.75 per 100 ft^3. Before implementing the zero discharge system, Poly-Plating was using 78,000 gal of water per day. Now, the company consumes 880 gal per day to make up the for the evaporative loss in the plating process and for the office, kitchen, and rest rooms.
- **Fear** that the Lower Limit of Detection (LOD) will become the discharge limit.
- **Increasing raw materials prices.** Poly-Plating needed to cut costs to stay competitive.

Waste Minimization Successes

Poly-Plating's efforts in waste minimization have focused on:

- **Recovering hydrochloric and nitric acid** using acid recovery units.
- **No plating shop waste water discharge to the city sewer system**.
- **Dialyzing its electroless tanks**. In a regular plating shop, says Poly-Plating, a normal electroless nickel bath is disposed of after six regenerations. At Poly-Plating, no nickel bath has been disposed of for five years.
- **Minimizing its caustic waste stream.** Poly-Plating uses superfiltration and cleans the tanks annually.

Future Plans

As time and funds become available, Poly-Plating plans to:

- Improve the membrane efficiency and make them thinner. Poly-Plating is working with the University of Massachusetts to develop stronger and more selective membranes.
- Create a zero discharge air system.
- Deal with the caustic tanks using a diffusion dialysis system. Currently, the caustics destroy the membranes used.

3.10.2 Poly-Plating Site Visit, concluded

Enablers

The following factors contributed to the implementation of waste minimization best practices:

- The cost of city water and sewer systems is a strong incentive to cut usage.
- The company owner takes a personal interest in waste minimization and pursues improved technology at his own expense.
- Few levels of management result in open, direct communication. When the company owner was experimenting with changing system pressures, he caused pump problems. The employees were not afraid to tell him to stop creating system problems.
- Shop size allows flexibility.
- Employees take great pride in the fact that Poly-Plating is not a polluter.

Barriers

The following factors were identified by Poly-Plating representatives as barriers they have encountered in their waste minimization efforts:

- There is a lack of continuity between city, state, and federal agencies.
- There is very little information available on the membrane technology used by Poly-Plating. Poly-Plating feels that they have become the experts in this field.
- More time is needed to engineer and implement change. As an operating job shop, there is not enough time for research and development.
- More funding is needed to further develop the membrane technology.

3.10.3 Valley Plating

Introduction

Valley Plating, located in Los Angeles, California, performs nickel and chrome plating and zinc plating on steel parts and uses sulfuric acid for stripping, pickling, and electroactivating.

Sulfuric Acid Extension

Two years ago, the shop began using Ambienol C® as an inhibitor to slow down the rate at which the iron dissolves in the acid. Because of the constant dragout and slower dissolution rate, the iron reaches an equilibrium at a much lower concentration than if no inhibitor was used. As a result, the bath never reaches an objectionable iron content, which would force the shop to dump the acid bath. Valley Plating has used the same sulfuric acid bath for two years. The shop uses a filter to purify the sulfuric acid, replenishes it, and uses the acid in pickling baths.

Product Quality

The shop has experienced improved product quality since the addition of the inhibitor. Valley Plating uses a 1.5% concentration of Ambienol C®. The shop uses a higher concentration of sulfuric acid at a higher temperature than previously. However, the higher concentration (14-15% instead of 7-8%) is more cost-effective because of the lower reject rate.

Inhibitor Description

Ambienol C® is an electroless pretreatment process that removes scale, oil, and surface smut, and is manufactured by Metalline Chemicals Corporation. The solution may be used with hydrochloric and sulfuric acids.

Future Plans

The shop loses a lot of sulfuric acid through dragout. However, Valley Plating is planning a new line that will use a slow counter-flow rinse to capture dragout.

3.11 Step 11: Communicate Results

Overview

This section presents the Best Management Practices (BMPs) learned from the site visits.

Normally, Step 11 of the benchmarking methodology includes implementing improvements and monitoring the results. In this case, implementation is not within the project scope. Section 3.10 provides the results of the site visits and this section lists the best management practices used by the partners so that individual sites may create their own implementation plans.

3.11.1 Best Management Practices Observed at Lorin Industries, Inc.

Best Management Practices

The following best management practices were observed at Lorin Industries:

- Provide cross training in jobs so workers can perform a variety of functions and expand their process expertise.
- Use reclaimed materials when possible; for example, using lime from an old pit created by a former manufacturer to neutralize sulfuric acid waste instead of purchasing new NaOH.
- Seek alternate uses for manufacturing end products; for example, using sludge containing phosphorous as a fertilizer.
- Empower employees to decide how they will complete the task. Work teams are given an assignment and the team decides on the division of labor.
- Upgrade existing equipment (for example, installing longer-lasting valves, pumps, and filters) to improve long-term performance.
- Seek continuous improvement. Always look for ways to improve performance.
- Work with regulators, especially on the local level, to improve communication and working relationships.
- Provide support for innovation and environmental consciousness from the highest level of management to the floor level.

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3.11.2 Best Management Practices Observed at Poly-Plating, Inc.

Best Management Practices

The following best management practices were observed at Poly-Plating:

- Create your own technology when current technology does not perform the job you want to accomplish.
- Train production personnel in waste management techniques so employees understand the complete cycle.
- Encourage open, direct communication from employees. When the company president experimented with changing pressures, it caused pump problems on the electroplating lines. Employees were not hesitant to tell the president to stop experimenting.
- Use in-tank filtration units.
- Encourage employee's suggestions and implement them. The pitched bottoms of plating tanks were difficult to clean. One employee suggested adding a small metal cup to the bottom of the tank. The change was made, and now tanks are easier to clean.
- Make the plater responsible for the quality of the product. Poly-Plating does not have a quality inspector. Platers know that if the product is not right, it must be stripped and replated.

3.11.3 Waste Minimization Options for Plating Shops

Additional Research

In addition to the information learned on the site visits, the team also performed a brief literature search for best management practices and solutions to problems encountered in plating shops. This search was not intended to be comprehensive, but can be considered a starting point. Appendix C provides the results of that research. A comprehensive information source is *Pollution Prevention and Control Technology for Plating Operations* by George C. Cushnie Jr., which provides the results of a project sponsored by the National Center for Manufacturing Sciences and conducted in cooperation with the National Association of Metal Finishers.

☞ **OUTCOME OF BENCHMARKING STEP 11:**
Better rinse water control, recycle/recovery techniques, improved technology, and best management practices were documented for improved waste minimization of DOE plating shop operations related to sulfuric acid.

3.12 Step 12: Continue to Conduct Benchmarking of Process

Ongoing Process

Normally, benchmarking is an ongoing process. The best waste minimization technology today may be outmoded and outclassed by new developments. This step is not currently being pursued by the team at large because of cost and schedule constraints, but would be necessary for actual process improvements.

Changes Made by Participants

Through the benchmarking project, some of the participants learned new techniques and renewed their efforts to minimize waste streams at their facilities. Because of the ideas shared in this study:

- one participating site added an acid recovery unit to its shop;
- two other sites are hoping to buy an acid recovery unit; and
- another site is planning to add a deionizing column to improve current acid recovery efforts.

4.0 Conclusions and Recommendations

Results and Recommendations

Because results and recommendations are an integral part of the benchmarking effort, they are included in the main body of the report.

> See Sections 3.10 and 3.11 for the results of the benchmarking project for sulfuric acid waste and recommendations for best management

Learning Process

The benchmarking process is also a learning process. As the project progresses, the most important quality for a team to have is the ability to be flexible, to shift gears, and to handle the unexpected. This section is written for benchmarking project leaders or team members to help them anticipate and hopefully avoid pitfalls in future benchmarking efforts.

4.1 Lessons Learned

Modifying the Methodology

A full benchmark is a long and rigorous process; the team had to modify the benchmarking process to accommodate the needs of the customer, DOE management. Several steps of the benchmark process can be successfully modified but none can be eliminated. Implementation, which is a major part of traditional benchmarking, could not be accomplished with this project because the team used a consensus process rather than a specific process. The process information was gathered from a variety of sites so there was no way to write an implementation plan that would apply to more than one site.

Benchmarking Lessons Learned

The team reported the following lessons learned:

- Geographic differences present different barriers. For example, water is cheap and plentiful in Michigan but not in Massachusetts.
- It can be easier to minimize waste in a straight-forward production line, but difficult in a research and development environment.
- The diversity of DOE makes implementation of best practices difficult.
- One of the difficulties of this project was finding appropriate partners. Most of the shops contacted were not doing any waste minimization with sulfuric acid because the acid waste stream was used to balance the caustic waste stream for waste disposal purposes. Caustic recovery and acid recovery go hand-in-hand. To be effective, efforts to minimize waste need to include both waste streams.

Continued on the next page...

4.2 Value and Benefit

Greatest Benefit

The process experts felt that the greatest benefit of the benchmarking process was the opportunity to network with their peers and share process and operations information. Members of the interview team felt that the ability to go on-site provides information not available from telephone or written questionnaires. Some best practices and techniques learned in site visits are not part of the main interview, but provide helpful information about other waste streams and potential waste minimization solutions.

Value of Workshop

The participants felt the workshop helped them to:

- see new technology in actual working environments,
- learn new ideas through hearing about other sites' processes,
- gain a networking opportunity for sharing ideas, and
- understand differences among state environmental laws and regulations. For example, a practice that was followed in one state might not be allowed in another state.

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Using Benchmarking to Minimize Common DOE Waste Streams

Volume IV. Sulfuric Acid Waste in Plating Shops

Prepared for
U.S. Department of Energy
Office of Waste Management
Environmental Management
Waste Minimization Division

Prepared by
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Abstract

Finding innovative ways to reduce waste streams generated at U.S. Department of Energy (DOE) sites by 50% by the year 2000 is a challenge for DOE's waste minimization efforts. A team composed of members from several DOE facilities used the quality tool benchmarking to improve waste minimization efforts. First the team examined sulfuric acid generation and handling processes at their sites. Then team members developed telephone and written questionnaires to help identify potential "best-in-class" industry partners willing to share information about their waste minimization techniques and technologies. The team identified two benchmarking partners, Lorin Industries, Inc., in Muskegon, Michigan, and Poly-Plating, Inc., in Chicopee, Massachusetts. Lorin Industries recovers sulfuric and phosphoric acid, cutting costs of raw materials and waste disposal. Lorin also uses a multiple-squeegee, counter-current rinse process to reduce dragout and water usage. Poly-Plating has achieved zero plating

shop waste water discharge to the city sewer system using a combination of an acid recovery system, Donnan dialysis, a cross-flow water filtration system, and electrodialysis to remove nonmetallics. Both companies have improved product quality and cut costs of raw materials and waste disposal.

ACKNOWLEDGMENTS

This report represents the efforts of many participants who shared their talents, time, and resources to further DOE's waste minimization efforts. We thank the following for their contributions:

Industry partners and their representatives:

- Lorin Industries, Inc., Dr. Joseph Manhart, Senior Scientist; Jim Nalewick, Technical Manager; Peter Laus, Project Engineer; and John Papp, Vice President for Manufacturing.
- Poly-Plating, Inc., Ed Ondrick, President; Richard Carpenter, Consultant; and Anthony D'Amato, Research Engineer.

DOE sponsors:

- Kent Hancock and Ker-Chi Chang at DOE EM-334, and Oren Critchfield at DOE/AL

DOE plating shop process experts:

- Ronald Angona, Technical Associate I, Brookhaven National Laboratory, Upton, New York
- Patrick Borello, Technical Associate II, Brookhaven National Laboratory, Upton, New York
- Michael Brooks, Electrochemical Engineer, Los Alamos National Laboratory, Los Alamos, New Mexico
- Edward Martinez, Processing Engineer, Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
- Michael McHenry, Senior Engineer, Allied Signal Aerospace, Inc., Kansas City, Missouri
- Robert Mikkola, Plating Engineer, Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Y-12, Oak Ridge, Tennessee
- Chris Steffani, Metal Finishing Group Supervisor, Lawrence Livermore National Laboratory, Livermore, California

Executive Summary

Mission

Recent Executive Orders are challenging U.S. Department of Energy (DOE) facilities to prevent pollution at its source and to use recycled products. DOE continues to seek innovative ways to reduce waste streams generated at DOE sites by 50% by the year 2000.

Project Focus

Sponsored by the DOE's Waste Minimization Division (EM-334), the Benchmarking for Waste Minimization project (1) examines waste minimization techniques and technologies that have been used successfully to minimize plating shop waste, specifically sulfuric acid waste, and (2) provides this information to affected sites within DOE. Benchmarking was the methodology used for analyzing the internal processes and seeking partners that have successfully improved their waste minimization procedures.

This report describes the team findings of the best waste minimization practices for sulfuric acid in plating shops.

Benchmarking Definition

Benchmarking is the continuous process of improving products, services, and practices by identifying and understanding the current process, exchanging information with recognized leaders in the field, and implementing meaningful improvements.

Benchmarking is used by a variety of companies and organizations as a quality improvement tool. For this project, the following 12-step benchmarking process was used:

1. Identify process to be benchmarked
2. Establish management commitment
3. Identify and establish benchmarking team
4. Define and understand the process to be benchmarked
5. Identify metrics
6. Evaluate current performance
7. Identify potential benchmarking partners
8. Collect process data from potential partners
9. Analyze potential partners' data and choose partners
10. Conduct site visits
11. Communicate results
12. Continue to benchmark the process

Benchmarking Team

A benchmarking team evaluated the current internal processes used at several DOE facilities for plating shop sulfuric acid waste. The team created a process flow chart and defined process metrics. Using telephone surveys and written questionnaires, the team searched for industry partners with similar working environments that had addressed the problems that the team was investigating. The team found two benchmarking partners.

Continued on the next page...

Results

The team visited Lorin Industries, Inc. in Muskegon, Michigan, and Poly-Plating, Inc. in Chicopee, Massachusetts, to learn about their waste minimization practices.

Lorin Industries Results

Waste minimization practices at Lorin Industries include the following:

- Recovers sulfuric acid using a continuous purge process with an acid purification unit. The company avoids the cost of new sulfuric acid purchases and reduces its waste stream.
- Recovers phosphoric acid from the bright dip and electropolish line with decationizer units (DCU).
- Uses a multiple-squeegee, counter-current rinse process to reduce dragout and water usage.
- Uses reclaimed lime to perform neutralization.
- Uses a high-pressure plate and frame filter press to minimize the volume of waste sludge, saving transportation costs and landfill space.

Poly-Plating Results

Waste minimization practices at Poly-Plating include the following:

- Achieves zero discharge of plating shop waste water to the city sewer system. Using the combination of an acid recovery system, Donnan Dialysis, a cross-flow water filtration system, and electrodialysis to remove nonmetallics, the shop stopped discharging waste water in 1987.
- Recovers hydrochloric and nitric acid using acid recovery units of Poly-Plating's own design.
- Dialyzes its electroless tanks. No nickel bath has been disposed of for five years.
- Minimizes its caustic waste stream with superfiltration and scrupulous tank cleaning.

System Benefits

The partners reported the following benefits of waste minimization:

- Both companies report improved product quality because they have greater system control.
- The increasing costs of raw materials were strong drivers for both companies to increase their waste minimization effort. Both companies have reduced purchases of new acids.
- Lorin Industries was able to expand its operating lines without expanding its waste water treatment plant.
- Both companies reduced costs for water and sewer services. Lorin has reduced costs for landfill charges.

Contents

Figures

Tables

Acronyms and Definitions

BMP	Best Management Practices
DOE	U.S. Department of Energy
ES&H	Environment, Safety and Health
H_2SO_4	Sulfuric acid
MMES	Martin Marietta Energy Systems
SNL/CA	Sandia National Laboratories, California
SNL/NM	Sandia National Laboratories, New Mexico
WMin	Waste Minimization
WWTP	Waste Water Treatment Plant

1.0 Introduction

1.1 Background

Executive Orders

Executive Orders signed by President Clinton require federal government agencies to prevent pollution and to use recycled products. Executive Order 12856 states that "It is the national policy of the United States that whenever feasible, pollution should be prevented or reduced at the source." Executive Order 12873 focuses on federal acquisition, recycling, and waste prevention and is intended "to strengthen the role of the Federal Government as an enlightened, environmentally conscious and concerned consumer."

DOE Waste Minimization Mission

The U.S. Department of Energy (DOE) has placed a high priority on waste minimization and pollution prevention, encouraging waste generators to develop programs and request adequate resources to effect long-term savings. To provide a strategy for meeting these priorities, the DOE created the Waste Minimization/Pollution Prevention Crosscut Plan (DOE, 1994). The plan states that DOE's waste minimization (WMin) mission is

> "To reduce generation and release of DOE multi-media wastes and pollutants by implementing cost-effective waste minimization and pollution prevention technologies, practices, and policies, with partners in government and industry while conducting the Department's operations in compliance with applicable environmental requirements."

DOE Objective

This benchmarking project helps to accomplish one of the major DOE Crosscut Plan Strategic Objectives which is "to identify and develop technologies and exchange information." The DOE can enhance the effectiveness of WMin efforts by exchanging applicable technologies and information with companies or organizations that are already successful in their WMin/Pollution Prevention approach. A secondary DOE objective is to work closer with U.S. industry.

Waste streams that are common in the DOE complex are logical targets for evaluation because the results can be shared across the complex.

Sponsor

The sponsor of this project is the DOE Waste Minimization Division, EM-334. The division's mission is to plan, coordinate, and develop a DOE-wide Waste Minimization and Pollution Prevention Program that results in a decrease in the amount of wastes produced by the DOE.

Benchmarking Approach

Benchmarking was chosen as the project approach because it

- has proven capabilities as a quality improvement tool,
- provides flexibility,
- may be applied to many different processes, and
- increases ties with U.S. industry.

For a complete definition of benchmarking and an explanation of the process, refer to *Using Benchmarking to Minimize Common DOE Waste Streams, Volume I, Methodology and Liquid Photographic Waste*, SAND93-3992, April 1994.

1.2 Purpose

Project Purpose

The project's purpose is to

- identify common waste streams throughout the DOE,
- provide a forum for the waste generators who produce the same waste stream at different DOE facilities,
- partner with private industry to learn the best waste minimization technologies that have been applied successfully to these waste streams, and
- provide this information to the DOE.

Benchmarking (a quality tool) provided the methodology for analyzing internal DOE site processes and for seeking industry partners that have successfully improved their own waste minimization efforts.

Report Purpose

This report describes the results of the benchmarking effort to identify the best waste minimization practices for managing the sulfuric acid waste stream.

1.3 Report Structure

This document is Volume IV in a series of waste minimization benchmarking project reports. Volume I includes the background, full project scope, benchmarking methodology, project details such as training and survey techniques, and results of the liquid photographic waste team. Volume II includes the results of the used motor oil team. Volume III includes the results of the aqueous cutting fluid team. The results of the sulfuric acid team are included in this report. Additional volumes will be added as other waste streams are studied.

Continued on the next page...

1.3 Report Structure, continued

The following table describes the report structure:

Report Section	Description
1	Project background and purpose.
2	The generic 12-step benchmarking methodology.

2.0 Benchmarking Methodology

Introduction

This section is a brief overview of the generic process of benchmarking, as defined by Sandia's Process Improvement/Benchmarking Team.

Benchmarking Definition

Benchmarking is the continuous process of improving products, services, and practices by

- identifying and understanding customer requirements and process performance,
- exchanging information with recognized leaders (internal and external to the organization),
- implementing meaningful improvements, and
- recalibrating the process by assessing the progress and monitoring trends and results.

Author Robert Camp has defined benchmarking as "the search for industry `best practices' that lead to superior performance" (Camp, 1989).

Benchmarking Steps

Figure 2-1 is a flow chart of the 12-step benchmarking methodology used at Sandia.

Figure 2-1. 12-Step Benchmarking Methodology

2.1 Defining the Benchmarking Process

Benchmarking Process

The following table shows the steps that comprise the benchmarking process. Steps 1 through 6 reflect internal process improvement. Steps 7 through 12 reflect external activities.

Step	Activity
1	**Identify Process to be Benchmarked** The process selected must be narrow enough in scope that it is manageable. The process must be important to the work or business function and be customer-focused because a substantial amount of resources (i.e., personnel, time, and funds) are required to conduct the benchmarking study. The result must improve the process and add value.
2	**Establish Management Commitment** Management is defined as the person(s) who has the authority to allocate resources (personnel, time, and funds) and who is ultimately responsible for the outcome of the benchmarking activity. Management • has the responsibility to make the effort to understand the fundamentals of benchmarking and to demonstrate a willingness to implement the results; • needs to support the team and its recommendations with resources, encouragement, and commitment; and • has the right to expect frequent updates from the benchmarking team (e.g., verbal reports, meeting minutes, reports, periodic presentations).
3	**Identify and Establish Benchmarking Team** The benchmarking team members include • **process experts** who have extensive knowledge of the process through their daily jobs (these are the people impacted by any changes); • **resource personnel** such as facilitators, trainers, quality or benchmarking consultants, information specialists, and technical writers; and • a **project leader** who guides the benchmarking process. The team may need training in benchmarking techniques, including process definition, the benchmarking process, quality tools, questionnaire design, and interviewing techniques. The team members must understand their roles and responsibilities and commit to a common team purpose or goal. The members must attend and participate in all meetings and complete their assignments. *Continued on the next page...*

Step	Activity
4	**Define and Understand the Process to be Benchmarked** The team defines the process through an understanding of important process elements: inputs, outputs, suppliers, and customers. The customer drives the business, and therefore, the team needs to understand the customers' wants, needs, and expectations. The team's final output for this step includes a process flow chart depicting the work flow and the relationships between people and organizations. The output from this step lays the foundation for the remainder of the benchmarking activity.
5	**Identify Metrics** The metrics must be meaningful to the process. Example metrics include customer requirements, cost, cycle time, and quality. Metrics, when possible, should be consistent with established standards (i.e., industrial, national, international). The process metrics aid in evaluating and assessing the current process. Strength and weakness trends developed from the metrics can identify areas for improvement and provide guidance and direction for selecting improvements to be implemented. Effective metrics provide guidance for developing survey tools for benchmarking partners.
6	**Evaluate Current Performance** The metrics help to identify the process areas to be improved and the nature of the improvements. The team may need to develop a decision matrix for ranking the improvements. A cost/benefit or return-on-investment analysis may be required to evaluate whether the benchmarking process should be continued. If the recommendation for implementation of the appropriate process improvements is made, it is necessary to monitor the trends and results. Benchmarking does not automatically assume that outside partners are required.
7	**Identify Potential Benchmarking Partners** Based on the metrics collected from the internal process, the team needs to identify and establish criteria for "best in class" partner selection criteria. The team can identify potential partners through numerous resources: database searches and contacts with external organizations, knowledgeable individuals, suppliers, and customers. The team needs to identify a sufficient pool of partners to determine the few they will visit. Partners that have better processes are not always easily found. A team may discover that their own processes are better than those of the potential partners. *Continued on the next page...*

Step	Activity
8	**Collect Process Data from Potential Partners** The team develops surveys to obtain preliminary information from potential partners. Surveys may consist of questionnaires, telephone interviews, or face-to-face interviews. (Normally, site interviews are reserved for Step 10.) The survey questions are based on the process metrics and criteria established for selecting partners. Up-front planning on how to analyze the quantitative and qualitative data is essential for developing good surveys.
9	**Analyze Data and Choose Partners** The preliminary data are used to select partners for site visits and interviews. The project leader compares the data gathered from the potential partners to the metrics and criteria set by the team. The final partner(s) must have a process that is applicable (in this study) to various DOE sites. The project leader should make direct comparisons of the data, process parameters, and constraints. The team analyzes the data and determines weighting and ranking criteria in order to select the final partners. If the team cannot find a partner that can provide substantial process improvements, the team needs to rethink the project. The team may decide • to repeat several steps, which includes revising the criteria, expanding the pool of potential partners, collecting new process data, and re-analyzing the data in the search to find appropriate partners; or • to conduct an internal evaluation; or • to terminate the benchmarking effort.
10	**Conduct Site Visits and Reanalyze Data** To gain the maximum benefit from partner site visits, careful and thorough preparation is essential. Preparation includes, but is not limited to, determining appropriate interviewees, assigning team interviewing roles, developing a list of questions and a meeting agenda, and determining how to handle the interview data. The site visit is an opportunity for two-way communication between the benchmarking team and each partner. During the site visit, the team conducts an in-depth interview. It is essential that the team develop an effective interview guide for each partner before the site visit. After all partners' information is collected, the quantitative and qualitative data are analyzed. A decision matrix may be used to identify and select the partners' practices to be incorporated. *Continued on the next page...*

Step	Activity
11	**Communicate Results** The team reports results to upper management and all involved parties and develops an action plan that describes the team's recommendations, methods for implementation, and implementation costs and schedule. The findings need to be adaptable to the process and the organization's culture and constraints. The improvements need to be monitored and evaluated.
12	**Continue to Conduct Benchmarking of Process** The best process today may not be the best process tomorrow. Depending on the amount of change in the process, customer requirements, competition, technological advances, and changing business practices, it is important to revisit the process, or specific aspects of the process, periodically.

Reference

This section is an adaptation of Section 2 of the report, *Benchmarking the Property Inventory Process at Sandia National Laboratories*, SAND92-2565 (Ramirez and Hill, 1993). It describes the generic process of benchmarking, as defined by Sandia's Process Improvement/Benchmarking Department.

Benchmarking Details

For details on the benchmarking methodology used for this project, refer to *Volume I, Methodology and Liquid Photographic Waste*, SAND93-3992, April 1994. For a copy of Volume I, contact the author at (505) 844-8956 or through the Environmentally Conscious Life Cycle Systems Department, Sandia National Laboratories, Albuquerque, New Mexico, 87185.

3.0 Sulfuric Acid Waste Benchmarking Results

Adaptation of Benchmarking Methodology

The 12 steps of the benchmarking methodology listed in Section 2 provide the framework for this project.

Benchmarking is a flexible process that lets each team adapt the standard procedure to the unique needs of the project.

The following chapter describes how the sulfuric acid team used the benchmarking process to collect information on Best Management Practices and other techniques and technologies for minimizing sulfuric acid waste within DOE.

3.1 Step 1: Identify Process to be Benchmarked

DOE's Waste-Generating Activities

Figure 3-1 illustrates four major types of waste-generating activities within the DOE, including:

- mission-related,
- waste management,
- environmental remediation, and
- infrastructure-related.

Infrastructure-related activities are the DOE's "landlord" activities as shown in the lower portion of Figure 3-1. Infrastructure-related activities were chosen because they have not yet received the same DOE-wide attention that the other three waste-generating activities have received. These activities produce DOE-wide waste streams that are also produced in outside industry. Therefore, they are ideal activities for benchmarking because appropriate industry partners should be easy to identify and locate.

Figure 3-1. Waste-Generating Activities in DOE

Identification of Common Waste Streams

Initial activities centered on collecting information on as many DOE waste streams as possible. Refer to Volume I for the detailed rationale for selecting plating shop waste as one of the waste streams for benchmarking.

Plating shop waste was chosen for benchmarking because it is a common concern throughout the DOE. Advances in waste minimization techniques and technology made by the U.S. plating industry are available to the DOE through benchmarking partnerships.

☞ **OUTCOME OF BENCHMARKING STEP 1:**
Process chosen for benchmarking:
- **Plating shop waste**

3.2 Step 2: Establish Management Commitment

Strong DOE Commitment

Because of DOE's emphasis on waste minimization, management commitment was a positive element in this project. The DOE sponsor for this project is the Waste Minimization Division, EM-334. Management support included the following:

- Headquarters provided project funding and guidance.
- The Albuquerque Field Office provided support through the WMin coordinator.
- Site management allowed the process experts the time to participate.
- Sandia management provided benchmarking expertise and trainers.

☞ **OUTCOME OF BENCHMARKING STEP 2:**
DOE management committed resources at national, regional, and local levels.

3.3 Step 3: Identify and Establish Benchmarking Team

Team Members

A benchmarking team usually consists of a project leader, process experts, management, and support personnel. Not all team members are required to participate at all times. Some team members may perform more than one role, as needed, for the team at large and for smaller subteams.

Finding Team Members

The project leader used the following sources to find benchmarking team members:

- Contacts within the DOE
- Proceedings from waste minimization conferences
- Discussions with site waste minimization coordinators

Roles and Responsibilities

The following table outlines suggested roles and responsibilities needed for a benchmarking effort.

Role	Responsibilities
Project Leader	Plan, organize, assign tasks, and oversee the benchmarking project.
Process Experts	Provide professional expertise on the target process during the workshops, contact industry partners, and conduct site interviews.
DOE Management	Set policy and provide support, personnel, time, and funding.
Trainers/Facilitators	Teach participants benchmarking techniques and lead workshops and work sessions to accomplish goals.
Information Specialist	Aid the search for potential benchmarking partners through database searches.
Writer/Recorder	Document the benchmarking process by recording workshop activities and provide support for project leader, as needed.

Continued on the next page...

Team Roster

The following table lists the plating shop team members:

Team Member	Title	Location
Ronald Angona	Technical Associate I	Brookhaven National Laboratory, Upton, New York
Pat Borello	Technical Associate II	Brookhaven National Laboratory, Upton, New York
Michael Brooks	Electrochemical Engineer	Los Alamos National Laboratory, Los Alamos, New Mexico
Diane Leek	Technical Writer	Tech Reps, Inc.
Victoria Levin	Project Leader, Environmentally Conscious Life Cycles Systems	Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
Edward Martinez	Process Engineer	Sandia National Laboratories/New Mexico, Albuquerque, New Mexico
Michael McHenry	Senior Engineer	Allied Signal Aerospace, Inc., Kansas City, Missouri
Robert Mikkola	Plating Engineer	Lockheed Martin Energy Systems, Oak Ridge National Laboratory, Y-12, Oak Ridge, Tennessee

☞ **OUTCOME OF BENCHMARKING STEP 3:**
Planning team, benchmarking team, and interview team successfully assembled.

3.4 Step 4: Define and Understand the Process to be Benchmarked

Process Foundation

Step 4 lays the foundation for all future activity. The team must define and understand the existing process before examining another's process. This step establishes the baseline from which to measure performance gaps.

Workshop Activities and Goals

The project leader, process experts, and support staff attended a workshop that provided training and a work session for the entire team, covering several benchmarking steps.

The goals of the first workshop were to

- Define and understand the process to be benchmarked (Step 4),
- Create a flow chart of the generic process (Step 4),
- Define the metrics of the process (Step 5), and
- Define the criteria for choosing potential partners (Step 7).

The table below summarizes the workshop activities. A detailed description of the activities follows the table.

Stage	Activity
1	Workshop facilitator directed team-building exercises to integrate the team into a cooperative, working unit.
2	Workshop facilitator trained the team in the benchmarking methodology so that team members understood the group process, the task, the commitment, and the work involved to complete the project.

Stage 1 — Team Building

Team Building

The team-building exercise resulted in a team name, motto, logo (see Figure 3-2), and mission statement.

Team Name	**The Minimizers**
Motto	**Close the Loop**

Figure 3-2 Logo for the Minimizers

Stage 2 — Train the Process Experts

The process experts were chosen for their knowledge of their fields and the tasks they perform in their daily jobs. However, they needed training in the benchmarking process.

Stage 3 — Create a Consensus Flow Chart

Process Flow Chart

The process experts came from a variety of sites that had different procedures, products, and customers. However, acid waste management was a common problem for all sites. The team needed to create a flow chart that expressed the process "big picture." The facilitator helped the group define the process parameters.

Process Parameters

All processes have the following common parameters:

- Inputs
- Suppliers
- Outputs
- Customers

The team used the parameters above to help them define the particular process that produces the sulfuric acid waste stream. For each parameter, the team listed ideas, and then evaluated each component to confirm that it was directly related to the sulfuric acid waste stream. The final lists are shown below.

Inputs

Inputs for the sulfuric acid waste stream include:

- **fresh sulfuric acid (H_2SO_4)**
- **filter cartridges**
- **energy (electricity)**
- **tanks--equipment**
- **part to be worked on**
- **anode/cathode material**
- **water**
- **labor**
- **make-up air**
- **other chemicals**
- **drag in from other processes**
- **miscellaneous contaminants (airborne, other)**
- **chemical analysis**

Suppliers

Suppliers for the sulfuric acid waste stream include:

- **chemical companies**
- **stockers**
- **operators**
- **utility companies**
- **laboratory technician for analysis**
- **part customer**
- **ambient environment**
- **container and equipment supplier**
- **other chemical processes**

Customers

Customers of the sulfuric acid waste stream include:

- waste treatment facility
- part customer
- waste customer
- employee/labor
- ES&H organization, management, regulators (EPA, DOE)
- storage facility

Outputs

Outputs of the sulfuric acid waste stream include:

- contaminated sulfuric acid
- parts
- dirty tanks
- rinse waters
- dirty filter cartridges
- empty containers
- fumes/air emissions
- documentation
- waste containers
- need for waste treatment, storage, disposal
- expired chemicals

Flow Chart

After the lists were finalized, the team created a flow chart (Figure 3-3) that diagrams the waste sulfuric acid generation and handling process.

☞ **OUTCOME OF BENCHMARKING STEP 4:**

Waste sulfuric acid process inputs, outputs, customers, and suppliers were identified. A flow chart of the generic process was completed.

Figure 3-3. Waste Sulfuric Acid Generation and Handling Process

3.5 Step 5: Identify Metrics

Definition

Metrics are the measures of the internal process. Metrics allow evaluation and assessment of existing performance and provide points of contrast after the lessons learned from the benchmarking activity have been applied.

Metrics

After the process flow chart was created (see Step 4), the facilitator led the team through a discussion of the metrics.

The group decided that the following metrics were relevant:

- pounds (lb) of sulfuric acid per part new
- lb of sulfuric acid per part waste
- maximum contamination levels for usable bath (that determine whether a bath is bad)
- operating concentration, temperature of H_2SO_4 bath
- production rate lb/month or sq ft/month
- total volume of H_2SO_4 waste generated
- number of dumps/month/year
- average bath capacity
- operating volume of the tank
- volume of new sulfuric acid used per year
- frequency of analysis
- number of employees
- type of bath (pickling, stripping, etc.)
- bath capacity
- tank size
- cost of treatment, storage, disposal
- cost of recycling equipment
- total volume of sulfuric acid waste and metal

NOTE: Not all the metrics are easily obtainable within DOE.

☞ **OUTCOME OF BENCHMARKING STEP 5:**
The team defined waste sulfuric acid process metrics that will provide the measures of the internal process.

3.6 Step 6: Evaluate Current Performance

Information Exchange

The team performed an informal evaluation of each site's performance by exchanging information and comparing activities and processes. Each process expert had the opportunity to discuss and explain site processes during the first workshop. A summary of sulfuric acid use at the participating DOE plating shops is shown in Table 3.1.

Plating Shop Site Visit

One of the team meetings was held at Lawrence Livermore National Laboratory (LLNL), enabling team members to see the waste minimization efforts at that plating shop. At LLNL, the waste minimization efforts fall under three main categories:

- Substitution
- Segregation
- Minimization/recycling

Substitution

LLNL's substitution waste minimization efforts are listed below:

- Replaced a cyanide-based copper strike with a pyrophosphate copper strike to retain the use of a copper strike in the main shop
- Replaced a sulfuric acid anodizing system with an oxalic acid hard anodizing system
- Replaced a nitric hydrofluoric acid desmut with a ferrous sulfate deoxidizing bath
- Switched to a non-cyanide chemical conversion coating
- Switched to a pressure washer instead of a vapor degreaser and got rid of an organic solvent
- Replaced a hexavalent chromium deposit with a tertiary nickel tungsten boron deposit

Segregation

LLNL's segregation waste minimization efforts are listed below:

- Moved all cyanide-related processes to a cyanide room. Removed cyanide from all other waste streams, reducing cost of handling.
- Segregated work by metal lines. LLNL has a separate line for copper, nickel, and anodizing. Unfortunately, LLNL is not able to extract metals for recycling because electrowinning is considered a treatment method in California and the laboratory is not authorized to perform treatment.

Minimization/ Recycling

LLNL's current minimization/recycling waste minimization efforts are listed below:

- Remove free oil with a membrane filtration system, which cuts LLNL's alkaline detergent waste stream from 400 gallons (gal) to 5 gal of effluent annually.
- Recycle sulfuric acid with dialysis membrane system.

Continued on the next page...

Minimization/ Recycling, continued

LLNL's current minimization/recycling waste minimization efforts are listed below: (continued)

- Minimize electricity use. In the past, all of the heaters, exhaust fans and equipment ran all the time. As part of an energy conservation program, shop personnel turn off the heaters and all equipment at night. A computer system automatically turns on the equipment at 6 a.m., before the workers arrive. The computer system saves $60,000 a year in electrical costs.
- Minimize water use by using a three-step washing process. (See Dragout/Rinse Tanks below.)
- Electroless nickel solution membrane system allows unlimited metal turnovers without disposal.
- Minimize spills with in-tank filters and pumps that keep all equipment over the tank. All filtration equipment for removal of airborne particulate matter is right in the tank.
- Use ultrasonic machines (combined with a detergent solution) that scrubs parts better than manual cleaning and produces less waste.

Dragout/Rinse Water

The dragout/rinse water waste minimization efforts are listed below:

- LLNL uses a spray and dip rinse process:
  - Use a spray rinse that rinses the chemical back into the tank (heat evaporates extra water)
  - Use a spray rinse into a dragout rinse tank.
  - Use an immersion rinse in static rinse tank. (Conductivity is maintained by automatic methods.)
  - Use a hot deionization rinse for the final rinse (maintained automatically).
- LLNL uses a cold vaporization process for rinse water recycling.
- The deionized water system uses a mixed bed resin and has carbon filters to remove organics and ultraviolet lamps to kill bacteria.

☞ **OUTCOME OF BENCHMARKING STEP 6:**

- **Individual team members shared information on each site's process and established network contacts for future problem solving.**

3.7 Step 7: Identify Potential Benchmarking Partners

Search Parameters

"Criteria" are defined as standards on which a judgment or decision may be based (Webster's, 1985). The team developed criteria to be used to identify appropriate potential partners. Defining criteria limited the search to partners that fit the team's needs.

Criteria

The plating shop team defined the following criteria for potential partners. A potential partner must:

- **generate H_2SO_4 waste.**
- **have common operations with DOE (pickling, etchback, etc.)**
- **use at least 500 gal of H_2SO_4 per year.**
- **know how much H_2SO_4 is used in a year and how much H_2SO_4 waste is produced in a year (mass balance).**
- **recycle H_2SO_4 or minimize it.**
- **have a minimum 25-gal tank size.**
- **have a 100-gal total capacity with at least 2 turnovers per year**
- **have deionization capability.**
- **have a waste minimization program.**

Information Sources for Identifying Potential Partners

A variety of methods and sources for identifying potential partners, including the following, were used:

- Literature search by an information specialist
- Process experts' suggestions
- Contacts through customers or suppliers
- Trade associations or publications

> ☞ **OUTCOME OF BENCHMARKING STEP 7:**
> **A list of 54 potential partners was identified.**

3.8 Step 8: Collect Process Data from Potential Partners

Data Collection Methods

In benchmarking, the main tool for gathering initial process data from potential partners is a questionnaire, either oral or written. Both types were used for this project.

Questionnaire Development Training

The benchmarking team learned questionnaire development techniques and how to define the questions to pose to potential partners.

Refer to Volume I, Appendix B, for an abbreviated training guide on questionnaire development techniques. Refer to Appendix A in this volume for the final telephone and written questionnaires used in this project.

Questionnaire Development Process

The group discussed what information would help them find benchmarking partners. The group needed two questionnaires:

- a telephone questionnaire to act as a filter to determine industry partner interest and broad suitability, and
- a written questionnaire that would elicit detailed information to help determine the final candidates for site visits.

Results

Of the 54 initial contacts made by the sulfuric acid team by telephone, 3 of the companies

- had processes that were appropriate for comparison to the DOE's process defined by the process experts, and
- were willing to participate.

Written questionnaires were sent to these companies. Of the 3 written questionnaires sent, 3 were returned. (This return rate of 100% exceeds the average return rate of 30-60% for prescreened written questionnaires.)

Problems Encountered

One of the difficulties of this project was finding appropriate partners. Most of the potential partners contacted were not minimizing sulfuric acid waste because the acid waste stream was used to balance the caustic waste stream for waste disposal purposes.

> ☞ **OUTCOME OF BENCHMARKING STEP 8:**
> **The team conducted 54 telephone questionnaires. Three written questionnaires were sent to potential partners.**

3.9 Step 9: Analyze Potential Partners' Data and Choose Partners

Choosing Benchmarking Partners

To choose final partners, the questionnaires were evaluated to determine if respondents:

- Showed a major decrease in disposal volume after implementation of new process
- Had ideas or technology that provided new information
- Had extended the life of sulfuric acid baths

☞ **OUTCOME OF BENCHMARKING STEP 9:**
The benchmarking partners chosen for the sulfuric acid waste stream were:

- **Lorin Industries, Inc. in Muskegon, Michigan**
- **Poly-Plating, Inc. in Chicopee, Massachusetts**
- **Valley Plating, Inc. in Los Angeles, California**

3.10 Step 10: Conduct Site Visits

Team Visits Partners

The interview team, a subset of the benchmarking team, received training on interview techniques, rules of conduct, and agenda development skills. The interview team visited Lorin Industries in Muskegon, Michigan, and Poly-Plating in Chicopee, Massachusetts, to gather information on best management practices and processing techniques for sulfuric acid. The project leader visited Valley Plating, Inc., in Los Angeles, California.

- For an abbreviated training guide on on-site interviewing techniques, refer to Volume I, Appendix D.
- For the plating shop team's final interview question set, refer to Appendix B of this document.

3.10.1 Lorin Industries, Inc. Site Visit

Company Introduction

Lorin Industries, Inc. of Muskegon, Michigan, is the world's largest volume coil anodizer of aluminum. Anodizing, an electrolytic process using sulfuric acid, converts the surface of the aluminum to a porous aluminum oxide, which may be colored using dyes or by plating metals into the pores. The finished coils are used by other manufacturers to produce lighting sheet for parabolic reflectors; spacer bar used between the panes of thermopane windows; shutters for diskettes, and architectural, electronic, and miscellaneous items.

Production Lines

Six production lines operate continuously as coils of aluminum unwind at the starting point, pass through various treating stations, and rewind as finished coils. Production lines run 24 hours a day, seven days a week. As a coil unwinds, the continuous sheet of aluminum is subjected to a series of baths and rinses. At the end of the production line, the coil is rewound, inspected for quality, and shipped.

Sulfuric Acid Recycling

The sulfuric acid concentration of 26% is maintained in the anodizing tank. The anodizing tank provides a continuous purge, with the overflow moving into a purge tank. From this tank, the solution is pumped to the acid purification unit (APU) for recycling. The APU holds sulfate on resin, allowing aluminum ions to pass through to waste. A water cycle recovers the sulfuric acid. The recycled acid flows to a holding tank, and then it is added back into the anodizing tank as fresh acid is needed. Figure 3-4 depicts the recycling process.

Figure 3-4 Lorin Industries' Sulfuric Acid Recycling Process

Lorin uses continuous addition of recycled sulfuric acid to maintain the aluminum at a level close to 3 to 6 grams per liter. Titration with sodium hydroxide (NaOH) indicates when manual additions are required to maintain the concentration of sulfuric acid. If the purge was not performed, the aluminum concentration would build up and the acid concentration would drop. Metallic ions other than aluminum are removed along with the aluminum in the recovery unit.

3.10.1 Lorin Industries Site Visit, continued

Sulfuric Acid Recycling, continued

The purge rate is increased or decreased based on the results of chemical analysis, which is performed every eight hours. Autotitration is used for the acid analysis and atomic absorption is used for checking the aluminum concentration. Lorin has an in-house laboratory with full-time analysts.

The byproducts of the APU system are recovered sulfuric acid and a waste stream containing aluminum and sulfuric acid.

Rinse Waters

To reduce dragout, Lorin uses a multiple-squeegee, counter-current rinse (MSCCR) system that provides rinsing while minimizing water usage. As the continuous aluminum web moves up toward the next process tank, it passes through several sets of squeegee rolls. Water is sprayed only below the top squeegee. Water runs down the sheet and over the squeegee below and back onto the web. Each squeegee prevents most of the rinse water from traveling up the web. Spray is pumped onto the incoming sheet from the bottom of the tank. Water runs down over the three sections of the MSCCR. A deep well (immersion) rinse in the next tank is the source of rinse water to the MSCCR. City water is sprayed onto the outgoing sheet.

However, sulfuric acid is not recovered from rinse waters. Currently, the concentration of sulfuric acid in rinse water is so low and the cost of rinse water disposal is so low that Lorin is not ready to purchase the equipment and dedicate labor to run and maintain this type of system.

Sulfuric Acid Loss

Not all sulfuric acid is recaptured for anodizing. Sulfuric acid **loss** occurs through:

- adhering to the aluminum coil
- APU waste
- rinse waters

Disposal of Waste

Rinse water from the sulfuric acid processes is sent to the on-site waste water treatment plant (WWTP). The WWTP performs a pH adjustment with lime, then flocculates, clarifies, and filters the waste water before releasing it to the sewer for treatment in the Muskegon County waste water management system.

All plant liquid wastes (largely acidic) are combined in the wastewater system and neutralized using lime. Lorin acquires lime that was generated as a byproduct of a previous acetylene manufacturer. The Michigan Department of Natural Resources (DNR) had been seeking a method to remove the lime, a cast-off from an old manufacturing process. This need led to a cooperative effort. Several area companies are using this low-cost resource.

3.10.1 Lorin Industries Site Visit, continued

Production Quality

Production quality has improved since the introduction of the purge bath by maintaining a lower and more constant aluminum content in the anodizing solution.

Worker Involvement

There are two main jobs on the production lines:

- processors who handle the coils and keep the web moving and
- control men who handle the chemical balances and baths.

In the past, a worker was assigned one role and performed that role only. Two years ago, Lorin changed the way management assigned work. Now, a shift team has the responsibility for doing the job. The team decides how to divide the work. Workers are cross-trained and may switch roles from day to day. Lorin does not have a union. Promotions from hourly to salary status often come from within.

Quality control inspectors and waste handlers are separate teams from production workers. Waste handlers run the neutralization clarification system and the acid recovery systems and handle chemical receipts and sludge removal.

Drivers for Waste Minimization Policy

The drivers for Lorin's waste minimization policy were:

- Reduce costs of the manufacturing process by buying less raw materials, in this case sulfuric acid and phosphoric acid.
- Reduce disposal costs by reducing volume of waste going to a landfill.
- Reduce costs of water and sewer charges.
- Expand the number of operating lines without increasing the load on the on-site WWTP. Lorin wanted to expand its manufacturing capabilities, but the clarifier already was operating at capacity. The company did not want to spend additional money to expand its WWTP.

3.10.1 Lorin Industries Site Visit, continued

Waste Minimization Success Summary

Lorin Industries' efforts in waste minimization have focused on:

- Sulfuric acid recycling
- Phosphoric acid recycling
- Using reclaimed lime to perform neutralization
- Using a multiple-squeegee, counter-current rinse system to minimize water usage
- Using high pressure plate and frame filter presses to minimize volume of waste sludge. The press enables longer cycles to increase solids content of sludge from about 25 to 40%, reducing the volume for disposal.

The following describe Lorin's successes in the waste minimization of acid waste streams:

- **Recovers sulfuric acid** using a continuous purge process with an acid purification unit manufactured by Ecotech of Pickering, Ontario, Canada. The APU handles 600 gal per hour. The company estimates that it recycles 14 million pounds of sulfuric acid solution every year, saving approximately $252,000 per year in avoided costs for buying new sulfuric acid. Also, Lorin made technical changes to the APU to optimize the cycle volumes for Lorin's concentrations of acids. Lorin also installed longer-lasting valves, pumps, and filters. With the addition of two new production lines, Lorin has purchased another APU for anodizing sulfuric acid recovery.

- **Recovers phosphoric acid** from the bright dip process and electropolish line with decationizer units (DCU) also manufactured by Ecotech. Lorin's internal volume was so low that it now buys waste phosphoric acid rinse water from another company's bright dip process and uses this rinse water, further reducing costs compared to buying new phosphoric acid. The Michigan Department of Natural Resources helped Lorin incorporate the waste rinse water into the process.

- **Uses reclaimed lime**, rather than the traditional sodium hydroxide (NaOH) for neutralization of sulfuric acid waste from rinse waters. The reclaimed lime is less expensive than NaOH. However, it is a slurry that requires longer contact time with the acidic waste than NaOH requires. Because the total waste stream at Lorin tends to be more acid than caustic, Lorin does not use sulfuric acid to balance the waste stream, as some anodizers do.

- **Uses a multiple-squeegee, counter-current rinse** concept to reduce water usage. See previous Rinse Waters section.

3.10.1 Lorin Industries Site Visit, continued

Future Plans

As time and funds become available, Lorin plans to implement the following:

- A system to capture a first rinse that is concentrated enough to recover sulfuric acid using ion exchange and evaporation.
- Any rinse tank using incoming and outgoing fresh water sprays should be modified to catch the runoff from the outgoing sprays and pump it to incoming sprays, which would result in half of the water usage per rinse station.
- Improve squeegee effectiveness by 1) assuring a tight wrap of the sheet to the squeegee, 2) using the proper squeegee hardness to most effectively remove the solution, and 3) finding a way to use offset squeegees instead of "on the exit roll" squeegees in more process tanks.
- Implement a caustic recovery system that would recycle sodium hydroxide and make a salable aluminum hydroxide.
- Instead of disposing of the phosphate-containing sludge from the combined wastewater treatment system, sell the sludge as fertilizer. Work is currently underway with Michigan Tech and Michigan State to develop this concept.
- Hire a full-time environmental manager to concentrate on waste minimization.
- Possible manufacture of alum from the APU waste stream and aluminum hydroxide from the caustic recovery system.

Enablers

The following factors contributed to the implementation of waste minimization best practices at Lorin:

- The company owner supports waste minimization efforts when the cost is justified.
- Management is responsive to suggestions.
- The company encourages a team approach to completing work. Workers are cross-trained and can perform different jobs as needed. The maintenance workers can perform welding, pipe fitting, and a variety of tasks, rather than requiring a special job category.
- The Michigan Department of Natural Resources, the state regulators, provides assistance.
- Focusing on one product enables the squeegee and counter-current rinse process.

3.10.1 Lorin Industries Site Visit, concluded

Disenablers

The following factors were identified by Lorin Industry representatives as disenablers they have encountered in their waste minimization efforts:

- The low cost of water and sewer services does not encourage water use reduction or minimizing discharge to the sewer.
  - Water is cheap and plentiful in Muskegon.
  - The cost of sewer disposal is approximately $.03/gal. It is hard to justify the cost of a rinse water reuse system when disposal is so cheap.

- More time is needed to engineer and implement change.

- Operators and lower management are resistant to change: "We've always done it this way" mentality.

- The risk of clogging spray rinses and reducing productivity is not worth the effort to reuse rinse waters because of the high calcium content of the water. Aluminum hydroxide, a byproduct of anodizing, is hard to clarify. It could clog spray nozzles in the cascade. A filtering device might allow Lorin to reuse water for some rinses, but is not currently planned.

- Shutting down a production line to make a machine modification is a major ordeal but it is necessary to implement change. Better coordination is needed between engineering, purchasing, operators, and maintenance to make the most effective change.

- Upper level management support for waste minimization is strong, but sometimes priorities get in the way. Business decisions have to be made, such as, "Should we put in Line 8 or a caustic recovery system?"

3.10.2 Poly-Plating, Inc., Site Visit

Company Introduction

Poly-Plating, Inc., of Chicopee, Massachusetts, is a plating shop that employs 16 employees in the production of nickel-plated parts. The company stopped discharging liquid waste from the plating shop to the city sewer system on Sept. 12, 1987. The system enabling closed loop operation was designed and developed by the company owner and employees. Incoming city water usage has been reduced to 880 gal a day, down from 78,000 gal per day.

Production Lines

The shop has three electroplating lines and an on-site laboratory that performs all necessary chemical analyses. A chemist performs a daily analysis for rinse water quality, including iron, copper, and nickel content. Oven calibration is the only technical service provided by an outside source. All plating processing tanks have in-tank filtration units. Rinse tanks have hand-nozzle spray rinses.

Zero Wastewater Discharge

In response to ever-stricter requirements imposed by the city of Chicopee, Poly-Plating began seeking zero discharge technology in 1983. Dissatisfied with the technology that was on the market at that time, Poly-Plating began designing and building their own equipment. The result is a zero waste water discharge system that has the following basic components:

- **Acid recovery system** that uses ion-exchange membranes arranged in a stack for diffusion dialysis. As the acid solution moves through the stack, acid molecules migrate through the membrane. Two end products result: a recovered acid solution that is 90% of the original strength, and a depleted solution containing the contaminant metal (in this case, nickel). The recovered acid is returned to the production line. Poly-Plating evaporates the depleted solution to increase the concentration and runs the solution through the recovery system a second time.

- **Donnan dialysis** that removes nickel from the rinse water using ion-exchange membranes. (This unit can target specific cations or anions for removal and concentration.) It is an alternative to conventional ion-exchange technologies with the added advantage of continuous usage, with no regeneration downtime. The Donnan dialysis unit performs: (1) deionization of closed-loop process water, (2) recovery of metal salts from low concentrations (less than 1 part per million (ppm)), and (3) nonadditive pH adjustment.

- **Cross-flow filtration system** uses a membrane filtration process that separates suspended solids from waste water.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Zero Wastewater Discharge, continued

Components of the zero waste water discharge system (continued):

- **Electrodialysis** that removes the nonmetallics present in the rinse water, such as sodium, potassium, sulfates, and chlorides. The unit performs ion exchange utilizing alternating sequences of cation membranes and anion membranes to separate and concentrate dissolved salts out of the rinse water.

- **Electroless nickel dialysis recovery system** that selectively removes bath impurities that build up during normal operation, allowing the bath to be used indefinitely.

Closed Loop System

A constantly moving cycle of 28,000 gal of water moves from the rinse tanks through a series of pits in a closed-loop system. The contaminated rinse water moves through a series of four pits:

- Pit #1 receives all contaminated rinses and aerates and breaks down all organics.
- Pit #2 uses a Donnan dialysis unit to remove nickel.
- Pit #3 adjusts the pH and chlorinates the water, as needed.
- Pit #4 uses an electrodialysis unit to remove nonmetallic anions and cations (nonmetals such as sodium, potassium, sulfates, and chlorides). Purified water returns to the rinse tanks. This step also performs a final pH adjustment (balanced to pH 6.2).

A shop layout showing the integration of the acid recovery units, the rinse water pit system, and the plating lines is shown in Figure 3-5. The shop design incorporates a gently sloping floor underneath the plating processing tanks. One pump is needed to recirculate all water.

Acid Recycling

An acid recovery system serves each one of the three electroplating lines. For lines using hydrochloric acid, the recovery system is placed at the acid activation point. For the nickel plating line, the acid recovery unit is linked to the nitric acid tank that is used for overnight passivation of the electroless nickel tank.

System Capacity

The system was designed to run unattended and to accommodate three days of recovered materials so no one would need to come in over the weekend or on holidays. The system had its most stringent test one Saturday when a worker started a task, left a water hose running in a tank, and answered the telephone before the task was finished. He left the building, forgetting the running water. When the crew opened the shop Monday morning, the tank had flooded and water was running down the sloped floor into the pits. The system processed all runoff; no water left the shop; and no permanent or costly damage resulted from the mistake.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Applications

Poly-Plating uses the acid recovery system for recovering:

- hydrochloric acid from stainless steel and titanium pickling, and metal cleaning baths and cation exchange regenerant solutions.
- nitric acid from rack stripping, rework stripping, and tank passivation.

However, the processes described have applications for all mineral acids commonly found in plating shops, for example:

- sulfuric acid from aluminum anodizing, steel pickling, or metal etching.
- phosphoric acid from electroplating and bright dipping.

Production Quality

Production quality has improved since the system was installed. In the winter, city water feeds into the building at 38°F. Ambient rinse water in Poly-Plating's recycled rinse water system is 60°F. Every six months, the City of Chicopee adds chlorine to the water, which introduces rust into the shop. Now, because of the low volume of added city water, constant temperatures are maintained, the small amount of rust is filtered with a cartridge filter, and the shop avoids seasonal problems presented by city water.

Worker Involvement

Four workers are certified to use and maintain the equipment. The equipment does not require a high level of technical expertise to operate or maintain. Systems are operated by production personnel.

Disposal of Waste

The system waste products are described below:

- Liquid nickel salts, the byproduct of the electrodialysis unit and the Donnan dialysis unit, are disposed of as uncontrolled nonhazardous materials. (1000 gal per year)
- Liquid effluent from the acid recovery system is stored in 55-gal drums on site. Poly-Plating plans to use it for experimenting with more selective membranes. Other users of the system may perform waste treatment on site, recover metals, or neutralize and filter the liquid, which could be disposed of as a nonhazardous waste.
- All system filters are disposed of as hazardous waste, as well as gloves or materials used for spill clean-up.
- An alkaline proprietary strip is disposed of as non-hazardous waste (370 gal per year.)

System Benefits

The benefits of the system are:

- New acid purchases were cut 99% from 1989 levels. For example, in 1989, Poly-Plating bought 100,000 lb of nitric acid. In 1994, the company bought two 55-gal drums of nitric acid, approximately 800 lb.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

System Benefits, continued

The benefits of the system are: (continued)

- Poly-Plating avoids escalating city water and sewer charges, permits, testing charges, etc. The company estimates an avoided cost of $75,000 per year from the water charges alone.

- The reject rate has dropped significantly since the new technology was implemented.

- Poly-Plating is classified as a Level 1 Vendor. The company receives an increased amount of work because it is a zero wastewater discharge shop. Customers have less potential liability.

- The system is over-engineered for the volume of work in the shop. The cross-flow filters are used only when Poly-Plating has a spill. Initially, when city water was used, the cross-flow filters were used to clean the incoming water from the city system. Now, a small 10-inch cartridge is used to filter the city water used to make up for the loss from evaporation. At 1 ppm of nickel, the Donnan unit is shut off. The unit is restarted when the nickel content reaches 10 ppm.

- A second company, Zero Discharge Technologies, resulted from the system development.

Drivers for Waste Minimization Policy

The drivers for Poly-Plating's waste minimization policy were:

- **Requirements from federal, state, and city sources.** State regulations were tighter than federal regulations, and city regulations were more rigorous than state regulations. As time goes on, Poly-Plating expects these regulations to become more stringent. For example, the allowable level for nickel in discharge waters is 2.54 parts per million (ppm) in the Chicopee area, and 1.0 ppm in the Boston area.

- **Dissatisfaction with the inflexibility of the bureaucracy.** The company president was strongly motivated by the desire to be free of officials. For example, the city was charging Poly-Plating $8,500 per year to duplicate testing that Poly-Plating was already required to perform. Poly-Plating eliminated that cost when it achieved zero sewer discharge.

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3.10.2 Poly-Plating, Inc., Site Visit, continued

Drivers for Waste Minimization Policy, continued

The drivers for Poly-Plating's waste minimization policy were (continued):

- **Increasing costs of public utilities.** In 1983, when the company began to look for alternative solutions, incoming city water was $.20 per 100 ft^3 with no additional charge for sewer discharge. In 1995, incoming city water is $1.20 per 100 ft^3 and sewer discharge fees are $1.75 per 100 ft^3. Before implementing the zero discharge system, Poly-Plating was using 78,000 gal of water per day. Now, the company consumes 880 gal per day to make up the for the evaporative loss in the plating process and for the office, kitchen, and rest rooms.

- **Fear** that the Lower Limit of Detection (LOD) will become the discharge limit.

- **Increasing raw materials prices.** Poly-Plating needed to cut costs to stay competitive.

Waste Minimization Successes

Poly-Plating's efforts in waste minimization have focused on:

- **Recovering hydrochloric and nitric acid** using acid recovery units.

- **No plating shop waste water discharge to the city sewer system**.

- **Dialyzing its electroless tanks**. In a regular plating shop, says Poly-Plating, a normal electroless nickel bath is disposed of after six regenerations. At Poly-Plating, no nickel bath has been disposed of for five years.

- **Minimizing its caustic waste stream.** Poly-Plating uses superfiltration and cleans the tanks annually.

Future Plans

As time and funds become available, Poly-Plating plans to:

- Improve the membrane efficiency and make them thinner. Poly-Plating is working with the University of Massachusetts to develop stronger and more selective membranes.

- Create a zero discharge air system.

- Deal with the caustic tanks using a diffusion dialysis system. Currently, the caustics destroy the membranes used.

3.10.2 Poly-Plating Site Visit, concluded

Enablers

The following factors contributed to the implementation of waste minimization best practices:

- The cost of city water and sewer systems is a strong incentive to cut usage.
- The company owner takes a personal interest in waste minimization and pursues improved technology at his own expense.
- Few levels of management result in open, direct communication. When the company owner was experimenting with changing system pressures, he caused pump problems. The employees were not afraid to tell him to stop creating system problems.
- Shop size allows flexibility.
- Employees take great pride in the fact that Poly-Plating is not a polluter.

Barriers

The following factors were identified by Poly-Plating representatives as barriers they have encountered in their waste minimization efforts:

- There is a lack of continuity between city, state, and federal agencies.
- There is very little information available on the membrane technology used by Poly-Plating. Poly-Plating feels that they have become the experts in this field.
- More time is needed to engineer and implement change. As an operating job shop, there is not enough time for research and development.
- More funding is needed to further develop the membrane technology.

3.10.3 Valley Plating

Introduction

Valley Plating, located in Los Angeles, California, performs nickel and chrome plating and zinc plating on steel parts and uses sulfuric acid for stripping, pickling, and electroactivating.

Sulfuric Acid Extension

Two years ago, the shop began using Ambienol C® as an inhibitor to slow down the rate at which the iron dissolves in the acid. Because of the constant dragout and slower dissolution rate, the iron reaches an equilibrium at a much lower concentration than if no inhibitor was used. As a result, the bath never reaches an objectionable iron content, which would force the shop to dump the acid bath. Valley Plating has used the same sulfuric acid bath for two years. The shop uses a filter to purify the sulfuric acid, replenishes it, and uses the acid in pickling baths.

Product Quality

The shop has experienced improved product quality since the addition of the inhibitor. Valley Plating uses a 1.5% concentration of Ambienol C®. The shop uses a higher concentration of sulfuric acid at a higher temperature than previously. However, the higher concentration (14-15% instead of 7-8%) is more cost-effective because of the lower reject rate.

Inhibitor Description

Ambienol C® is an electroless pretreatment process that removes scale, oil, and surface smut, and is manufactured by Metalline Chemicals Corporation. The solution may be used with hydrochloric and sulfuric acids.

Future Plans

The shop loses a lot of sulfuric acid through dragout. However, Valley Plating is planning a new line that will use a slow counter-flow rinse to capture dragout.

3.11 Step 11: Communicate Results

Overview

This section presents the Best Management Practices (BMPs) learned from the site visits.

Normally, Step 11 of the benchmarking methodology includes implementing improvements and monitoring the results. In this case, implementation is not within the project scope. Section 3.10 provides the results of the site visits and this section lists the best management practices used by the partners so that individual sites may create their own implementation plans.

3.11.1 Best Management Practices Observed at Lorin Industries, Inc.

Best Management Practices

The following best management practices were observed at Lorin Industries:

- Provide cross training in jobs so workers can perform a variety of functions and expand their process expertise.
- Use reclaimed materials when possible; for example, using lime from an old pit created by a former manufacturer to neutralize sulfuric acid waste instead of purchasing new NaOH.
- Seek alternate uses for manufacturing end products; for example, using sludge containing phosphorous as a fertilizer.
- Empower employees to decide how they will complete the task. Work teams are given an assignment and the team decides on the division of labor.
- Upgrade existing equipment (for example, installing longer-lasting valves, pumps, and filters) to improve long-term performance.
- Seek continuous improvement. Always look for ways to improve performance.
- Work with regulators, especially on the local level, to improve communication and working relationships.
- Provide support for innovation and environmental consciousness from the highest level of management to the floor level.

Continued on the next page...

3.11.2 Best Management Practices Observed at Poly-Plating, Inc.

Best Management Practices

The following best management practices were observed at Poly-Plating:

- Create your own technology when current technology does not perform the job you want to accomplish.
- Train production personnel in waste management techniques so employees understand the complete cycle.
- Encourage open, direct communication from employees. When the company president experimented with changing pressures, it caused pump problems on the electroplating lines. Employees were not hesitant to tell the president to stop experimenting.
- Use in-tank filtration units.
- Encourage employee's suggestions and implement them. The pitched bottoms of plating tanks were difficult to clean. One employee suggested adding a small metal cup to the bottom of the tank. The change was made, and now tanks are easier to clean.
- Make the plater responsible for the quality of the product. Poly-Plating does not have a quality inspector. Platers know that if the product is not right, it must be stripped and replated.

3.11.3 Waste Minimization Options for Plating Shops

Additional Research

In addition to the information learned on the site visits, the team also performed a brief literature search for best management practices and solutions to problems encountered in plating shops. This search was not intended to be comprehensive, but can be considered a starting point. Appendix C provides the results of that research. A comprehensive information source is *Pollution Prevention and Control Technology for Plating Operations* by George C. Cushnie Jr., which provides the results of a project sponsored by the National Center for Manufacturing Sciences and conducted in cooperation with the National Association of Metal Finishers.

☞ **OUTCOME OF BENCHMARKING STEP 11:**
Better rinse water control, recycle/recovery techniques, improved technology, and best management practices were documented for improved waste minimization of DOE plating shop operations related to sulfuric acid.

3.12 Step 12: Continue to Conduct Benchmarking of Process

Ongoing Process

Normally, benchmarking is an ongoing process. The best waste minimization technology today may be outmoded and outclassed by new developments. This step is not currently being pursued by the team at large because of cost and schedule constraints, but would be necessary for actual process improvements.

Changes Made by Participants

Through the benchmarking project, some of the participants learned new techniques and renewed their efforts to minimize waste streams at their facilities. Because of the ideas shared in this study:

- one participating site added an acid recovery unit to its shop;
- two other sites are hoping to buy an acid recovery unit; and
- another site is planning to add a deionizing column to improve current acid recovery efforts.

4.0 Conclusions and Recommendations

Results and Recommendations

Because results and recommendations are an integral part of the benchmarking effort, they are included in the main body of the report.

> See Sections 3.10 and 3.11 for the results of the benchmarking project for sulfuric acid waste and recommendations for best management

Learning Process

The benchmarking process is also a learning process. As the project progresses, the most important quality for a team to have is the ability to be flexible, to shift gears, and to handle the unexpected. This section is written for benchmarking project leaders or team members to help them anticipate and hopefully avoid pitfalls in future benchmarking efforts.

4.1 Lessons Learned

Modifying the Methodology

A full benchmark is a long and rigorous process; the team had to modify the benchmarking process to accommodate the needs of the customer, DOE management. Several steps of the benchmark process can be successfully modified but none can be eliminated. Implementation, which is a major part of traditional benchmarking, could not be accomplished with this project because the team used a consensus process rather than a specific process. The process information was gathered from a variety of sites so there was no way to write an implementation plan that would apply to more than one site.

Benchmarking Lessons Learned

The team reported the following lessons learned:

- Geographic differences present different barriers. For example, water is cheap and plentiful in Michigan but not in Massachusetts.
- It can be easier to minimize waste in a straight-forward production line, but difficult in a research and development environment.
- The diversity of DOE makes implementation of best practices difficult.
- One of the difficulties of this project was finding appropriate partners. Most of the shops contacted were not doing any waste minimization with sulfuric acid because the acid waste stream was used to balance the caustic waste stream for waste disposal purposes. Caustic recovery and acid recovery go hand-in-hand. To be effective, efforts to minimize waste need to include both waste streams.

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4.2 Value and Benefit

Greatest Benefit

The process experts felt that the greatest benefit of the benchmarking process was the opportunity to network with their peers and share process and operations information. Members of the interview team felt that the ability to go on-site provides information not available from telephone or written questionnaires. Some best practices and techniques learned in site visits are not part of the main interview, but provide helpful information about other waste streams and potential waste minimization solutions.

Value of Workshop

The participants felt the workshop helped them to:

- see new technology in actual working environments,
- learn new ideas through hearing about other sites' processes,
- gain a networking opportunity for sharing ideas, and
- understand differences among state environmental laws and regulations. For example, a practice that was followed in one state might not be allowed in another state.

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Table C-1 Additional Waste Minimization Options for Plating Shops

Problem	Options	Discussion
Treatment of cyanide electroplating solutions - acutely toxic and hazardous to the environment.	Replace cyanide electroplating solutions with qualified substitutes.	• Some substitutions meet or surpass the adherence, solde density, and conformance to precision patterns found in e solutions.(Hughes et al. 1992) • Elimination of cyanide-containing compounds has the pot simplifying operations and decreasing the volume of wast • Eliminates environmental effects produced by cyanide. (H • Direct substitutes do not result in large changes of the pro
	Gold Sulfite plating process is a suitable replacement for cyanide salt processes previously used for electrodeposition of gold during microelectronics fabrication.	Pros: • Experience, comparison testing and evaluation showed th successful replacements for cyanide baths. (Hughes et al • Technical advantages included good conductivity, smooth underplating, and very good throwing power resulting in g microelectronic features. (Worobey et al., 1991) Cons: • Less stable than the cyanide-based complex and therefor conditioning of bath chemistry to achieve longevity and hig al., 1992) • Sulfite solutions contain toxic brighteners such as As, Se,

Problem	**Options**	**Discussion**
	Copper pyrophosphate - replaces traditional cyanide copper strike solutions.	Pros: • Eliminates sampling for cyanide in rinse tanks and treating part of the waste stream. (Hughes et al., 1992) • Bath can remain uncontaminated and effective as long as the ratio of pyrophosphate to copper is controlled. (Hughes et al., 1992) • Neutral pH of the solution does not degrade the substrates. Cons: • Longer plating time of 30 minutes for the copper pyrophosphate solution compared to 10 minutes for the copper cyanide solution. (Hughes et al., 1992)

Table C-1 Additional Waste Minimization Options for Plating Shops, continued

Problem	Options	Discussion
Treatment of cyanide electroplating solutions - acutely toxic and hazardous to the environment, continued	*Cadmium Sulfate* -obtained by reacting cadmium with excess sulfuric acid to obtain cadmium sulfate, plus a commercial brightener.	Pros: • Provided adherent electrodeposits demonstrating successful replacement of cyanide solutions with sulfate based solutions. (Hughes et al., 1992) • Reduced plating time by 50%. (Hughes et al., 1992) Cons: Replaced one toxic substance for another (Cd). (Hughes et al., 1992) • Extremely temperature sensitive. Must be maintained below 80 degrees Fahrenheit to maintain optimum bath composition and chemistry. (Hughes et al., 1992)
Palladium chloride baths become contaminated with copper over time	*Ion exchange* resins remove the copper contamination from these solutions.	Allows the palladium chloride solution to be reused indefinitely while the added hydrochloric acid maintains pH. (Woodside and Prusack, 1991)
Copper pyro-phosphate baths become contamin-ated with organic materials.	*Activated carbon* can remove organic impurities by processing the copper pyrophosphate through it.	Solutions may then be used indefinitely with ammonium hydroxide added to maintain pH. (Woodside and Prusack, 1991)
Reduction of hazardous waste while maintaining product quality.	*Reprocessing sulfuric acid* - used in semiconductor etching, often in combination with a strong oxidizing agent such as hydrogen peroxide or ammonium persulfate.	One plant showed overall sulfuric acid usage reduced by 90-95% through the cascade bath configuration and acid reprocessing. (Content, 1991)

Table C-1 Additional Waste Minimization Options for Plating Shops, continued

Problem	Options	Discussion
Copper-containing sludge requires hazardous waste treatment	*Advanced reverse osmosis system* - copper-recovery system using ion-exchange columns and electrowinning technologies	Pros: • Membranes do not require pH adjustments. (Brown, 1992) • Microprocessor manages reverse osmosis (RO) membranes, influent, permeate, temperature, flow rate, and conductivity. (Brown, 1992) • Can reconcentrate dilute solutions to at or near bath strength without evaporation or additional concentration technology. (Brown, 1992) • Continuous flow of etch solution allows continuous removal of impurities while maintaining oxidant strength. • Produces salable scrap copper metal. Cons: • Initial capital expenditure may be prohibitive.
Rinse water discharge and recovery of nickel plating bath	Eliminate rinse tanks using a *spray-rinse configuration.*	• Rinse water discharge reduced by 83%

Problem	Options	Discussion
Regenerating chromic acid and sulfuric acid etching solutions.	*Diaphragm cell* equipped with cation-selective membrane to oxidize chromium at the anode and to remove copper, the major metallic contaminant at the cathode. (Soboroff et al., 1979)	Pros: • Conserving a valuable secondary resource, Cr, which is a costly imported ore. (Soboroff et al., 1979) • Major reduction in chromium-containing effluent. (Soboroff et al., 1979) • Reduced waste solution treatment and disposal costs. (Soboroff et al., 1979 and Spotts) • Before entering the diaphragm cell, filtering etchants through a polypropylene cartridge reduced membrane fouling and lowered cell resistance. • Etchant can be used for a year without replacement as opposed to spent etchant discarded after three days of use (Spotts) • Better product quality control - regenerated etching solution remains constant and is superior to that of the untreated etchant. (Spotts) • Reduced sodium di-chromate consumption (Spotts) • Reduced drag-out losses due to etchant continually being regenerated (Spotts) • Copper by-product recovery - can be sold as a secondary copper product (Spotts)

Table C-1 Additional Waste Minimization Options for Plating Shops, continued

Problem	Options	Discussion
Regenerating chromic acid and sulfuric acid etching solutions, continued.	*Precipitation* of copper-bearing waste acid - addition of oxalic acid ($H_2C_2O_4$) results in production of CuC_2O_4 precipitate and concurrent regeneration of HNO_3. Reclaimed for recycling by precipitating major metal impurities and regenerating acid. Zr is removed as Na2ZRF6 and copper is removed as CuC2O4. (Brouns and Stewart)	Pros: • Copper is removed from solution, HNO_3 is regenerated and can then be recycled to the metal-finishing process. • After precipitation, copper-bearing acid can be mixed with spent milling solution for reclamation using distillation. • CuC_2O_4 precipitate can be neutralized and dewatered. The heat generated during neutralization will thermally degrade CuC_2O_4 to a less toxic CuO for disposal. • Reduces volume of waste requiring disposal, reduces potential hazard to the environment, and lowers the cost of raw materials and disposal. • Strip solution waste volume reduced by 90%. • Chemical milling solution and any residual waste acid from etching and stripping can be reclaimed using distillation with H_2SO_4. (Brouns and Stewart) Cons: • Irreversible dilution of the acid does occur during the metal-stripping operation and therefore at a specified concentration of HNO_3, the copper bearing acid would require discharge. (Brouns and Stewart)
Metal-bearing acid	Use *precipitation and distillation* to detoxify acid by removing heavy metals and to reclaim acid for recycle. (Brouns and Stewart) Nitrates and fluorides present as free acid and metal salts can be reclaimed as acid.	• >80% of HNO_3 that is free of SO_4 should be recovered with a 40% or greater reduction in volume. • Reclaimed HNO_3 is suitable for recycle to any of the metal-finishing operations. • Distilled water can be used as make-up water for other processes. • Heavy metals, solids and other contaminants are retained in the H_2SO_4 bottom liquid. • Reduces volume of waste required disposal, reduces potential hazard to the environment, and lowers the cost of raw materials and disposal. (Brouns and Stewart)

Problem	**Options**	**Discussion**
	Reduce or eliminate the waste at its source - Spent acidic etchant is batch treated to adjust pH and precipitate dissolved metals then discard as industrial waste water. (Edwards et al., 1992)	Pros • Dissolved metals may be recovered for potential sale. Cons • Industrial waste water must still be disposed of.

Problem	**Options**	**Discussion**
Reducing acid wastes	• *Have a spill-prevention plan* • *Use ion exchange capability* - process all acid wastes with segregation according to metal content through resins. • *Recover washings and electrowin metal.* (Ulbrecht and Watts, 1992)	• Higher operating expenses. • Electrowinning may require RCRA permit.

Problem	**Options**	**Discussion**
Management of wastewater from nickel plating.	*Recycle nickel plating wastewater* - Mix nickel plating wastewater with an aqueous alkaline component to remove, by precipitation in the form of hydroxides, contaminating metal ions other than nickel. An ion exchange process treats the filtrate and an aqueous solution of nickel salts containing excess free sulfuric acid is obtained. Alkali is used to precipitate nickel hydroxides. A centrifuge filtration process is used. The nickel hydroxides are then added to the rest of the aqueous nickel salt solution for neutralization with sulfuric acid which forms nickel sulfate and the free sulfuric acid is then removed so as to obtain a highly concentrated nickel-sulfate solution. (Hyashi, 1977)	• Free sulfuric acid concentration reduced. • Highly concentrated nickel salt solution produced. • Most of the nickel can be recovered. (Hyashi, 1977)

Table C-1 Additional Waste Minimization Options for Plating Shops, continued

Problem	Options	Discussion
Separating plating chemicals from rinse waters	*Atmospheric evaporator* - requires pump to move the solution, a blower to move the air, a heat source, an evaporation chamber where solution and air are mixed, and a mist eliminator to remove any entrained liquid from the exit air stream. (Cushnie, 1994)	Pros: • Low capital cost. • Simple operation and low maintenance. • Very high recovery rates can be achieved. • No additional reagents are needed. • Small quantities of sludge are generated. • Reduces costs related to treatment and disposal, such as transportation Cons: • High energy requirement for heating solutions. • Discharging vented air outside of the shop may be a regulated source of air pollution. • Because moisture is exhausted to the atmosphere, it cannot be reused as rinse waters as with vacuum evaporators. • Evaporators return contaminants to the bath and may reduce bath life. • Spray/fog rinsing over the bath or fume suppressants are not compatible with atmospheric evaporators since they reduce the head room in the plating tank and limit the return of rinse water/drag-out.
	Vacuum evaporator - a distilling device that vaporizes water at low temperatures when placed under a vacuum. Unit consists of a boiling chamber which is under a vacuum, a liquid/vapor separator and a condensing system. (Cushnie, 1994)	Pros: • Applies to recovery of heat-sensitive chemicals, chemicals sensitive to air oxidation, low or ambient temperature plating solutions, and solutions that contain volatile components. • Reduces atmospheric discharge. • Operates at relatively low temperatures. • Advantageous with alkaline cyanide solutions, which build up carbonates more rapidly with atmospheric evaporators because the latter aerates the solution. • Applies in situations where atmospheric evaporators are either technically or economically impractical. Cons: • Some residuals generated (may be sent offsite to recycle). • Complex and more expensive to construct and maintain than atmospheric evaporators. • Not economically practical when large volumes of low concentrated solutions are involved.

Problem	Solution	Discussion
Separating plating chemicals from rinse waters, continued	*Ion exchange* - an ion from solution is exchanged for a similarly charged ion attached to an immobile solid particle (e.g., ion exchange resin). The strategy is to exchange somewhat harmless ions, located on the resin, for ions of interest in the solution (Cushnie, 1994).	Common applications of this technology include: • Treatment of raw water (e.g., city water) to produce high quality rinse water. • Chemical recovery from rinse water. • Treatment of plating baths to remove contaminants. • As a primary end-of-pipe treatment process. • As a polishing end-of-pipe treatment process to comply with stringent effluent limitations. Cons: • Not applicable to concentrated drag-out solutions or plating baths. • Cannot be used in a “bleed-and-feed” system, where spent bath is bled to the rinse water.
	Electrowinning - used to reduce the mass of inexpensive regulated metals (zinc, copper, lead), and cyanide being discharged to treatment. Used for gross metal recovery from concentrated solutions such as drag-out rinses or ion exchange regenerants (Cushnie, 1994).	Pros: • Reduces the quantity of treatment reagents used and sludge generated. • Recovers expensive common metals and precious metals. • Reduces overall process costs. Cons: • May be considered a treatment method that requires licensing. • Not sufficient as a stand-along technology to meet discharge standards. • Removes metals, but not all dissolved solids. Dragout solution must be purged to prevent build-up of dissolved solids.

	Reverse Osmosis (RO) - Used to purify raw water before use as rinse water, recover plating chemicals from rinse water, and polish wastewater treatment effluents (usually for reuse as rinse water). RO, also referred to as cross-flow filtration, is based on osmosis and ionic repulsion (Cushnie, 1994).	Pros: • Has the ability to concentrate dissolved salts. • It is an ambient temperature, low energy process. • Can be reused for rinse water. • Comparatively low capital and operating costs. • Quantity of residuals is low, and mostly restricted to used cartridge filters and reverse osmosis membranes. Cons: • Cannot tolerate significant concentrations of suspended solids. • Operates at higher pressures than micro- or ultrafiltration and usually requires a heavy gauge stainless steel housing. • Membranes can be fouled by precipitation products and/or suspended solids. • Does not sufficiently concentrate the chemicals for direct return in some applications.

Table C-1 Additional Waste Minimization Options for Plating Shops, continued

Problem	Solution	Discussion
Separating plating chemicals from rinse waters, continued	*Meshpad mist eliminators* - removes plating chemicals from the exhaust air from a plating tank. As part of the exhaust system ductwork, the mist eliminator reduces airstream velocity, permitting the droplets of plating solution to cling to the meshpads, removing them from the air stream (Cushnie, 1994).	• When used as a recovery technology, no residuals are generated. • Chemicals captured by the meshpads are returned to the process tank. • Meshpad mist eliminators can be dedicated to individual tanks. • Energy costs specific to exhaust fans and water circulation pumps.
Maintaining chemical integrity of baths.	*Filtration* - Removes suspended solids from plating and other metal finishing solutions which cause roughness and burning of deposits. Various equipment include: cartridge filtration, precoat filters, and sand or multimedia filters (Cushnie, 1994).	Pros: • Using a cleanable/reusable filter reduces expenses and waste from disposal of filter elements. • Extends the life of electrocleaners and the acid pickle. Cons: • Replacing filter media generates a solid waste that adds to the operating costs.

	Acid Sorption - applies to dilute to moderately concentrated acid solutions such as anodizing and pickling baths. Resins are used to absorb chemicals in surrounding solutions and the chemicals are subsequently desorbed with water. These reversible sorption processes include ion exclusion, ion retardation, and acid retardation. Removes dissolved metal contaminants from acid baths (Cushnie, 1994).	Pros: • Reduces acid usage. • Reduces neutralization treatment reagent usage. • Reduces interruptions in production. • Reduces process control variability caused by fluctuations in bath composition. Cons: • Does not recover all of the acid in a treated bath (~80-90%). • Process cannot be applied to highly concentrated acids. • Acids containing chromates should not be purified with this process. • Hydrochloric solutions containing zinc and lead should not be purified using this process. • By-products of the process require treatment.

Table 3.1 Summary of Sulfuric Acid Use at the Participating DOE Plating Shops

Topic	AlliedSignal Aerospace/KCD	Brookhaven National Laboratory	Lawrence Livermore National Laboratory	Los Alamos National Laboratory	Y-12, Oak Ridge, TN
Main Uses for Sulfuric Acid	Neutralization after persulfate bath used for micro-etch, and copper sulfate plating	Etch-back multi-layer boards	Activation and anodizing, copper and nickel plating baths	Copper plating bath and pickling bath. (Data refers to Target Fabrication Facility only.)	Pickling metals prior to plating, anodizing
Volume of Sulfuric Acid Use and Waste	Uses and disposes of approximately 970 gal/year	Uses and disposes of 2-3 gal/year	Uses 1000 gal/year resulting in 100 gal/year in waste	Disposed of 40 gal/year before acid recovery unit was added. Currently, 2 gal/year projected.	Uses and disposes of approximately 500-600 gal/year
Current Method for Handling and Disposing of Sulfuric Acid	Put waste in 350-gal carboys and ship to on-site waste treatment facility. Industrial waste pre-treatment facility neutralizes, floc-culates, separates and clarifies waste. Water goes to the sewer and the sludge is shipped to a hazardous waste landfill.	Used to neutralize the caustic waste stream.	Recycle in acid recovery unit. The acid waste byproduct is placed in 55-gal drums, sent to on-site treatment facility. On-site treatment facility neutralizes the waste, releases water to the sewer and flocculants to a hazardous waste landfill.	Added an acid recovery unit that can recycle all shop acids and has cut acid waste streams by at least 95%. The byproducts of the acid recovery unit will be used to neutralize caustics prior to sending to waste services at LANL.	Put waste in 55-gal drums, and ship to waste treatment facility.

Topic	AlliedSignal Aerospace/KCD	Brookhaven National Laboratory	Lawrence Livermore National Laboratory	Los Alamos National Laboratory	Y-12, Oak Ridge, TN
Future Plans	Has written a proprosal for acquiring an acid recovery unit. Possible project to work with mining companies to reclaim metals from sludge.	Currently, sulfuric acid waste is not a concern because of the low volume used in production.	Add a deionizing column for better acid recovery.	Planning to add an anodizing tank.	Would like to recover acid for reuse to save on paperwork, labor, and shipping expenses.