National Center for Manufacturing Sciences

Benchmarking Metal Finishing

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What You Will Find in This Report

This report is a picture, a handbook, and a roadmap. In it, you will find:

- A snapshot of the environmental state of the metal finishing industry at the start of the 21st century
- Some practical guidance—If you do metal finishing, you can see how your company compares with others in your business. You will learn how the best environmental performers do it: what kind of equipment they use, how they run their processes, and how they lock in their advantage.
- One vision of how the industry as a whole can improve its performance (with advantages for everyone).

You will also see how the best environmental performers can be top economic performers. Working clean not only *can*—but *does*—save money. You will learn how much the top performers are saving, and you will be able to draw your own conclusions about whether investment in pollution prevention and good work practices can pay off for you.

The report is divided into four chapters:

1. **The Benchmarking Survey** describes an extensive survey of the metal finishing industry and the questions asked. This chapter outlines the types of manufacturers that responded, and concludes with an overall summary of the results.
2. **Using the Survey Results** presents a more detailed analysis of the information that the survey provided. Direct use of the raw data shows the cost consequences of working clean. A ranking system helps make fair comparisons between companies running different processes and product mixes. And, you can use a system created to help you see how your own facility stacks up.
3. **Guide to Best Practices** summarizes how the best performers have achieved their results. This chapter provides detailed descriptions and convenient reference tables on a process-by-process basis. You can consult the tables to find both basic and advanced suggestions for ways to improve the processes you run.
4. **Roadmap for the Future** begins with where we, as metal finishers, stand as an industry, and considers where we want to go. And, this chapter provides one possible answer to the critical question: *How do we get there?*

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Background and Acknowledgments

What Is the *Benchmarking Survey*?

The Benchmarking Survey is an extensive study of the metal finishing industry, covering environmental performance and pollution prevention issues. The National Metal Finishing Resource Center (NMFRC) carried out the survey with the cooperation of the Surface Finishing Industry Council. This effort was accomplished with funding from the Environmental Protection Agency (EPA) under its Metal Finishing Sector Strategic Goals Program (SGP).

The Strategic Goals Program is a cooperative effort among the metal finishing industry, the EPA, and state and local regulatory agencies to achieve "cleaner, cheaper, and smarter" performance by voluntary improvement. Industry participants agree to work toward a set of environmental performance goals, and the agencies agree to work toward a more sensible and flexible regulatory policy for companies that are truly striving to go "beyond compliance."

What We Did

Working with representatives from industry, local and state governments, and the EPA, and with environmental specialists, we developed a detailed survey form. We sent out these forms to metal finishing shops to find out how they handled environmental issues, how much these issues cost them, and how well they were doing. The survey was carried out between April and October 1999.

Why We Did It

We wanted to obtain a broad overview of the range of environmental performance for the metal finishing industry as a whole. With this information, metal finishers will be able to determine where they stand in relation to their peers. The information will also help Strategic Goals Program review committees recognize those companies whose performance was superior when they began participating in the program and evaluate the progress of other companies.

We also wanted to find out just what it is that the best performers are doing right, and what factors make the most difference in achieving top performance. This "best practices" information will help all metal finishing facilities, including the participants of the Strategic Goals Program, determine the best ways in which to improve their efficiency and reduce their process and environmental costs.

Who We Are

The participation of many individuals from the metal finishing industry, the EPA, and the diverse viewpoints of all the stakeholders involved in the Strategic Goals Program provided great benefit to the survey.

- George Cushnie of CAI Resources, Inc. contributed his extensive process knowledge and technical insight, which are responsible for the depth of content in this report. The procedure used for ranking environmental performance could not have been developed without his understanding of the metal finishing industry and its view of the world.

- Edith Wiarda of the Michigan Manufacturing Technology Center (MMTC) applied her skill at statistical analysis, which is responsible for the degree to which useful information has been extracted from the survey data. The understanding of statistical methods can be difficult. If the reader finds the description of how the tools have been used as being reasonably clear in this report, the credit is due to her exemplary clarity of explanation.

- Christian Richter coordinated the efforts of the metal finishing industry.
- Carl Koch and his colleagues at the EPA were key players.
- Many participants in the Strategic Goals Program helped shape the survey.
- Personnel from 132 metal finishing companies provided the data for the survey.
- Scott Walker of *Products Finishing Magazine* and Michael Murphy of *Metal Finishing Magazine* helped the team reach the broadest number of shops possible with the survey.
- Paul Chalmer of the National Center for Manufacturing Sciences (NCMS) was responsible for overall program management, and provided much of the report narrative.
- Martha Swidersky, also of NCMS, edited and produced this final report document and, with her usual devotion and professionalism, has ably served as the reader's advocate.

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Acronyms and Abbreviations

Btu	British thermal unit
EPA	Environmental Protection Agency
g	gram
gal	gallon
HCD	high current density
ID	identification
kWh	kilowatt–hour
ℓ	liter
lb	pound
LCD	low current density
MEK	methyl ethyl ketone
MMTC	Michigan Manufacturing Technology Center
NCMS	National Center for Manufacturing Sciences
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NMFRC	National Metal Finishing Resource Center
NYSERDA	New York State Energy Research and Development Authority
P2	pollution prevention
PWB	printed wiring board
RO	reverse osmosis
SGP	Strategic Goals Program
SMOBC	solder mask over bare copper
SPC	statistical process control
ssf	surface square feet
TCE	trichloroethylene
TRI	Toxics Release Inventory
VOC	volatile organic compound
WWT	wastewater treatment
yr	year
°F	degree Fahrenheit

Chapter 1. The Benchmarking Survey

When we set out to survey the metal finishing industry, we faced two contradictory requirements. We wanted as broad a cross section of the industry as possible to provide a statistically valid picture of the industry as a whole. At the same time, we wanted to learn in detail about what was actually working best on the shop floor.

For a good response rate, we needed a survey that would not take long to complete, and would ask for information that most responders could easily find and report. But, for the detailed picture, we needed to go into greater depth, which meant a greater time commitment on the part of the responders.

Therefore, we carried out the survey in two phases:

- In Phase 1, we sent out a relatively simple form to more than 1,500 job shop plating facilities. We received 132 responses. This was a large enough number from which to draw firm conclusions about the responding population, and even to use statistical methods to deduce information about specific processes that most shops would not have been able to provide individually. (In any survey of this type, there is always a question of how well the shops that responded represent the industry as a whole. We discuss this question in detail in Chapter 1.)
- In Phase 2, we sent out more detailed forms to all the Phase 1 responders. Of these, 58 facilities completed the Phase 2 survey. Since we were interested in specific details, we followed up many of the Phase 2 responses with phone contacts to clarify and extend the information.

In this chapter, we present the questions asked in both phases. We profile the respondents, and consider how well they represent the industry as a whole. And we begin to put the results together.

One of the most valuable benefits of the statistical approach is the ability to deduce information from the entire collection of returns that is not available from any one individual. Most metal finishers know how much water they use each month, how much sludge they generate, how much electricity they use, and so on. But they typically use those resources for many different plating processes. They would find it excessively burdensome to keep this kind of information separately for each process they run. On the other hand, they can generally give a reasonably accurate estimate of what percent of their sales is generated by each of their processes.

With information from companies with many different mixes of products, we can estimate the expected amount of water and electricity to be used by each process and the expected amount of sludge to be generated, per dollar of sales, from each process. With the data available from the survey, we were able to obtain expected rates of resource usage for the six most common plating processes. The results presented in this chapter not only measure the overall performance of the industry on a process-by-process basis, but also allow any company to calculate what its expected resource usage rate would be with its particular mix of processes. In addition, we consider how other information reported on in the survey is related to environmental performance.

The actual survey forms used and a compilation of the responses we received are gathered in Appendices 1A and 1B to this chapter. Some of this information has been derived with specialized statistical techniques. Appendix 1C contains a detailed explanation of the methods used to analyze the data.

1.1 What We Asked in Phases 1 and 2

In the Phase 1 survey form, which is given in Appendix 1A at the end of this chapter, we asked for basic environmental data, including:

- Water use
- Sludge generation
- Organic chemical emissions rates
- Energy usage.

To put this information in context, we also needed to know some general process information, such as:

- A process profile, including a list of important processes carried out at the plant, the approximate fraction of sales or labor hours accounted for by each, and the percent of each process classified as rack, barrel, or "other"
- Production rates, measured as sales, labor hours, surface square feet, or amp–hours
- Wastewater treatment processes.

Finally, we asked for some basic business information, including:

- Annual sales
- Number of employees
- Geographic location
- Markets served
- Wastewater regulations applicable to the facility.

The Phase 1 information told us much of the "what," but did not get into the "why." With the Phase 2 survey, we wanted to determine how various management practices and other factors relate to environmental performance. Phase 2 focused on nine potential areas of influence:

1. Administrative measures
2. Training
3. Facility conditions
4. Use of written procedures
5. Use of recordkeeping
6. Energy reduction activities
7. Pollution prevention activities
8. Industrial hygiene activities
9. Costs and savings related to environmental factors.

1.2 Who Responded: a Profile of Survey Participants

A total of 132 metal finishing facilities participated in the Benchmarking Survey. This section presents a picture of these companies. We use the data they provided to answer several questions about the makeup of the survey population. Among the questions are:

- What processes do they carry out?
- What range of plant sizes is represented?
- How many participate in the Strategic Goals Program?
- What markets do they serve?
- What regulations apply to their operations?

1.2.1 Processes

One of the most basic ways to describe a metal finishing operation is to list the processes that it carries out. Many metal finishing companies run several processes; others specialize in one or two.

To see what kinds of companies participated in the survey, we will first list all the different processes that participants reported. We will see how many companies run multiple processes, and how many processes they run. And we will see which processes are the most widespread in terms of the number of shops that run them.

Table 1-1 lists all the metal finishing processes that the participating companies reported carrying out. In all, 31 processes are listed. As shown in Table 1-1, zinc plating is by far the most commonly reported process. It is carried out by 48.5% of the participants. In contrast, several processes are listed by only a single company. (Note that plants with unique processes were excluded from later analyses. We have no way of judging their performance relative to others.)

Table 1-1. 31 Processes Listed by Survey Participants

Process	Companies Reporting	
	No.	%
Zinc Plating	64	48.5
"Other" (as designated by the participant)	48	36.4
Nickel Plating	35	26.5
Decorative Chromium Plating	33	25.0
Electroless Nickel Plating	33	25.0
Anodizing (Sulfuric Acid)	29	22.0
Hard Chromium Plating	28	21.2
Phosphating	20	15.1
Passivation	20	15.1
Painting	19	14.4
Cadmium Plating	17	12.9
Precious Metals Plating	16	12.1
Chromating	16	12.1
Silver Plating	15	11.4
Black Oxide	15	11.4
Tin Plating	15	11.4
Copper Plating	12	9.1
Brass Plating	10	7.8
Electropolishing	9	6.8
Powder Coating	4	3.0
Bronze Plating	4	3.0
Tin-Lead Plating	3	2.3
Anodizing (Chromic Acid)	3	2.3
Mass Finishing	2	1.5
Chemical Milling	1	0.8
Derusting	1	0.8
Hot Solder Dip (Molten)	1	0.8
Iron Plating	1	0.8
Paint Stripping	1	0.8
Vacuum Coating	1	0.8
Other 2 (a company-specific list of several rare processes)	1	0.8

1.2.2 Multi-Process Operations

Most of the survey participants are multi-process operations. Table 1-2 shows that less than a quarter of the participants run only one process. A substantial number run six or more.

When comparing the environmental performance of one shop with another, we have to recognize that most shops do more than one thing. This

Table 1-2. Frequency of Multi-Process Operations

Number of Distinct Processes	Survey Participants	
	No.	%
1	31	23.5
2	20	15.1
3	22	16.7
4	19	14.4
5	10	7.6
6	14	10.6
7	7	5.3
8	4	3.0
9	1	0.8
10	2	1.5
11	1	0.8

complicates the comparison. But many of the 31 processes are relatively minor parts of a plant's operation. Suppose we look only at "significant" processes. Table 1-3 lists the 31 processes, as in Table 1-1. But instead of counting all the plants that run each process, it shows only the number of plants for which that process accounts for at least 20% of sales.

The processes beyond the top six are "significant" in fewer than 5% of the participating plants. For the rest of this section, we will concentrate on the top six processes only. They are:

1. Zinc Plating
2. Nickel Plating
3. Decorative Chromium Plating
4. Electroless Nickel Plating
5. Anodizing
6. Hard Chromium Plating.

1.2.3 Rack and Barrel Plating

Parts to be plated can be hung individually on racks or can be tumbled in a barrel. The barrel method is generally used for small parts. The survey requested information on the percent of sales resulting from barrel versus rack plating. The results for the six significant processes are summarized in Table 1-4. Only zinc has a really sizeable share of the work reported as barrel plating rather than rack plating. Nearly half of zinc plating sales comes from barrel plating;

Table 1-3. Frequency With Which Processes Account for at Least 20% of Facility Sales

Process	Companies for Whom Process Constitutes ≥=20% of Sales	
	No.	%
Zinc Plating	52	39.4
Decorative Chromium Plating	23	17.4
Hard Chromium Plating	21	15.9
Anodizing (Sulfuric Acid)	18	13.6
Electroless Nickel Plating	14	10.6
Nickel Plating	11	8.3
Precious Metals Plating	6	4.5
Phosphating	5	3.8
Painting	4	3.0
Silver Plating	4	3.0
Electropolishing	4	3.0
Chromating	3	2.3
Tin Plating	3	2.3
Copper Plating	3	2.3
Brass Plating	3	2.3
Passivation	1	0.8
Black Oxide	1	0.8
Cadmium Plating	1	0.8
Powder Coating	1	0.8
Bronze Plating	1	0.8
Iron Plating	1	0.8
Tin-Lead Plating	1	0.8
Vacuum Coating	1	0.8
Mass Finishing	1	0.8
Chemical Milling	1	0.8
Derusting	1	0.8
Paint Stripping	1	0.8
Hot Solder Dip (Molten)	1	0.8
Other 2 (a company-specific list of several rare processes)	1	0.8
Other (as designated by the participant)	0	0.0

Table 1-4. Average Percent of "Significant" Processes Carried Out in Rack vs. Barrel Mode

"Significant" Process	Average % Barrel Mode	Number of Plants With Barrel > 0%
Zinc Plating	44	40
Nickel Plating	24	4
Decorative Chromium Plating	4	3
Electroless Nickel Plating	26	10
Anodizing (Sulfuric Acid)	2	1
Hard Chromium Plating	0	0

40 shops report doing some zinc barrel plating. Electroless nickel, with the next highest share of sales from barrel plating, is carried out in only 10 shops. Zinc plating is the only process for which we have enough data for separate analyses of rack versus barrel.

1.2.4 Comparison Between Survey Respondents and General Population

Since participation in the survey was voluntary, the overall makeup of the set of participating shops may be different from the industry as a whole. It would be helpful to find some independent measures of the overall population of metal finishing establishments, so that we can compare the participating shops against them.

1.2.4.1 Plant Size

One good source for overall information is United States census data. While we would not expect to find details on plating processes in such data, we can find some general business indicators. One measure that we can use for comparison is the number of employees. In Table 1-5, we have divided the number of employees into eight ranges. For each range, we indicate the percent of survey participants, and the percent of all metal finishing establishments with that many employees.

Table 1-5. Distribution of Plants by Employment, Survey Participants vs. All U.S. Establishments

Number of Employees	Survey Participants, %	All U.S. Metal Finishing Establishments,* %
1–4	10.3	29.2
4–9	13.4	17.0
10–19	14.4	20.1
20–49	30.9	21.4
50–99	23.7	7.5
100–249	5.1	3.0
250–499	2.1	0.3
500+	0.0	0.0

* *Source:* U.S. Bureau of the Census, U.S. County Business Patterns, 1997, SIC 347.

Very small metal finishing operations did not respond to the survey in proportion to their number in the industry as a whole. Table 1-5 shows that 29.2% of U.S. metal finishing establishments have fewer than 5 employees. But only 10.3% of survey participants are that small. On the other hand, almost one-fourth of survey participants have between 50 and 99 employees, while only 7.5% of plants industry-wide are that large. Thus, the set of survey participants might not be representative of the very small shops, but may look more like the larger shops.

1.2.4.2 Participation in Strategic Goals Program

Another factor that may set survey respondents apart from the industry as a whole is participation in the Metal Finishing Strategic Goals Program (SGP). Program participants have already demonstrated both their willingness to provide information on their performance and a commitment to environmental improvement. We expected that SGP participants would account for a much larger proportion of survey responses than their proportion in the industry as a whole, and that this factor would make the survey group look correspondingly better in environmental terms than the industry in general.

We were partly right. SGP participants do make up a disproportionately large share of the survey group, comprising 56 of the 132 survey respondents (42.4%). In terms of the industry as a whole, SGP participants are much smaller group. About 300 companies had signed up to participate in the SGP when our survey was carried out. They would represent about 3% of the 10,000 metal finishing operations in the U.S. If we restrict the comparison to independent job shops, leaving out captive shops, the difference is not quite as large. SGP participants would comprise perhaps 10% of the 3,000 U.S. job shops. But either way, our sample population includes a very strong SGP contingent.

For that reason, it is important to analyze whether SGP participants score better on environmental performance than non-SGP firms. If so, then the survey results would provide an overly optimistic estimate of industry performance as a whole. As it turned out, SGP participants did not score any better or any worse, as a group, than non-SGP firms (see Section 1.3.3.4). Thus, while SGP participants are clearly overrepresented in our sample, the data indicate that no systematic bias results.

These findings contain two pieces of good news. Firstly, one possible outcome that had been of concern at the start of the survey was that almost all of the responses would be from SGP participants. Such an outcome would have limited the usefulness of the Phase 1 survey, which was undertaken to try to capture a picture of the industry in general, not just SGP participants. Since 57.6% of the survey participants were not SGP participants, the survey did indeed provide useful information about a somewhat broader group. (We still lack representation from the very smallest shops.)

The other piece of good news is more subtle. At first glance, it may seem discouraging that these SGP participants are no better than the rest of the industry. However, that is really a strength for the SGP. We know from independent SGP data that the SGP group taken by itself is indeed improving from year to year. What the Benchmarking Survey finding tells us is that the SGP is not simply taking the best of the metal finishing population and making it better. It is taking a reasonably representative cross section of metal finishers and raising that group's performance. This finding bodes well for the eventual success of the SGP as more metal finishers participate.

1.2.5 Other Descriptive Statistics

Survey participants are a diverse group in terms of the markets they serve, their regulatory requirements, and the extent to which they consider their business repetitive versus non-repetitive. These characteristics are summarized in the following subsections.

1.2.5.1 Markets Served

Table 1-6 lists a variety of different markets served by metal finishers, together with the number and percent of survey participants for whom each market accounted for at least 20% of sales. Almost one-third reported that at least 20% of their sales were to the automotive industry. Another quarter said that at least 20% of their sales were to machinery/industrial customers.

Table 1-6. Markets Served

Market	Survey Participants With at Least 20% of Sales to This Market	
	No.	%
Motor Vehicles	42	31.8
Machinery/Industrial	34	25.8
Other	27	20.4
Other (Non-Toys) Electronics	22	16.7
Fasteners	14	10.6
Aerospace/Aircraft	13	9.8
Hardware/Tools	13	9.8
Wire Goods and Pipes	11	8.3
Building/Construction	7	5.3
Military/Government	5	3.8
Other Household Items	5	3.8
Sporting Goods/Toys	4	3.0
Furniture	4	3.0
Household Appliances	3	2.3
Plumbing Fixtures	2	1.5
Medical	2	1.5
Jewelry	1	0.7

1.2.5.2 Regulatory Regime

Table 1-7 shows the categories of regulations under which survey participants operate. Fully one-third of survey participants indicated they are subject to local regulations that are more stringent than CFR 413 and 433 on at least one parameter. (Participants could indicate more than one category.)

Table 1-7. Applicable Wastewater Regulations

Wastewater Regulations	Survey Participants	
	No.	%
Electroplating (40 CFR 413)	55	41.6
Metal Finishing (40 CFR 433)	19	14.4
Combination of 413 and 433	14	10.6
Local Standards More Stringent Than 413 and 433	45	34.1
Other	5	3.9
Not Sure	12	9.1

1.2.5.3 Repetitive Work

Some metal finishers tend to run the same parts week after week, while others deal with a constantly changing variety of jobs. Since setting up for a new job often involves emptying and refilling tanks, cleaning equipment, and other resource-consuming activities, we reasoned that the degree to which a given facility's work was repetitive might influence its overall environmental performance.

We asked survey participants to tell us what percent of their sales resulted from repetitive work, which we defined as "nearly identical parts day-to-day, not requiring changes in production methods." In contrast, we defined non-repetitive work as "different types of parts every day," requiring "frequent changes in production." Their responses are summarized in Table 1-8. Roughly three-quarters of survey participants indicated that a majority of their work was repetitive rather than non-repetitive. Of the 132 participants, 128 responded to this question.

Table 1-8. Percent of Sales from Repetitive Work

Percent of Sales	Survey Participants	
	No.	%
0–10	12	9.4%
11–30	7	5.5
31–50	14	10.9
51–70	17	13.3
71–90	38	29.7
91–100	40	31.2

There may be many other interesting ways to characterize the survey participants. A detailed summary of the data collected during the survey is presented in Appendix 1B to this chapter for those interested in pursuing these questions. But we will turn now to the environmental performance data, to see what characteristics of the participants are associated with differences in environmental performance.

1.3 What We Learned

In this section, we begin to summarize what we learned from the survey participants about their environmental performance. We can find some information directly from the raw data. Most of the information in Section 1.2 comes directly from what the participants told us. But some of the most interesting information requires applying various mathematical tools to the data.

It is important to explain clearly what we are doing, and what assumptions we are making, when we use these tools. This section begins with a brief description of our approach. The intent is to give nonspecialist readers enough of an overview to be able to interpret and evaluate our conclusions. Readers interested in more depth can find a more detailed discussion in Appendix 1C to this chapter.

1.3.1 Overview of Our Approach

We need to use the mathematical tools for two reasons: one a problem; the other an opportunity:

- The problem: we need to compare similar factors or “apples with apples.”
- The opportunity: we want to put the data from many companies together to obtain more process-by-process details than any one individual company could provide.

1.3.1.1 Comparison of Similar Factors

The “apples with apples” problem is easily appreciated by metal finishers. No two metal finishing shops are in exactly the same business. Suppose two shops each use a million gallons of water per year, but for different process mixes and different types of parts. Even though they discharge the same amount of water, one might be running at peak efficiency while the other might have overlooked many opportunities for reducing water consumption.

That is the “apples with apples” problem. How can we compare the rate of water usage (or other environmental performance measure) of one shop with that of another? Can we put together the known facts about a company’s operations to be able to tell which one is operating efficiently and which is not?

The simplest way to compare two different shops is to find a common factor against which we would measure them. We would expect that a bigger operation will use more water. But how do we measure “bigger”?

- Sales per year? Then the plater with lower profit margins would be penalized because the shop generates less in sales for the same amount of processing. We want to measure the plating shop’s environmental performance, not its ability to command higher prices.
- Square feet of surface plated per year? That is a good measure from a technical standpoint, but very few shops have that information available, unless they run large numbers of similar parts.

Every other measure that can be devised has advantages and disadvantages. We addressed this dilemma by collecting information on several possible plant size measures. We then applied some statistical tests to see which ones worked best. The possible size measures are:

- Sales (in dollars per year)
- Value added
- Metal finishing shop labor hours per year
- Surface square feet of material plated per year
- Rectifier amp–hours used per year.

Most of these measures are familiar to metal finishers. Value added is similar to sales, but it subtracts the cost of raw materials and some other costs.

When we reviewed the data the participants were able to provide, we found that we had to eliminate two of the possible size measures with no further analysis. Only 28% of the participants had data on amp–hours, and less than 20% had data on surface square feet.

To evaluate the remaining three possibilities, we applied a statistical test. For each performance measure (water discharged, sludge generated, etc.), we calculated how much each shop generated per dollar of annual sales. For example, we looked at how many gallons of water were discharged per dollar of sales for each shop. If annual sales were the perfect comparison factor, our calculation would result in the same number for each shop. So, if the average turned out to be, for example, three gallons discharged for every dollar of sales, and if annual sales were a perfect measure, we could be sure that a shop with $2 million in annual sales would discharge six million gallons of water every year. However, annual sales is not a perfect measure. What we actually found was a scattering of gallons-per-dollar numbers around some average value. We used a statistical measure of variation (standard deviation) to measure the amount of scatter, and thus to rate how good a comparison factor annual sales actually is for our data set.

We repeated the calculations for the other two possible comparison factors for which we had enough data to use: water discharged per value-added dollar and water discharged per labor hour. We also ran the same calculations using several measures of environmental performance other than water discharged. Again, for each combination of environmental performance measure per each size measure, we computed the amount of variation in that number across all the shops.

We then made the assumption that the size measure giving the least variation in performance per size across all the shops was the most appropriate factor to use to compare one shop with another. Thus, in most cases, annual sales did turn out to be the best measure.

Here is another way to look at the same assertion. Suppose that all you knew about each shop was its annual sales, its annual value added, and its annual labor hours. Then, its annual sales would be the best number to use to predict its water discharge rate and other environmental performance measures. For this reason, we used annual sales as the plant size measure in the analysis that follows. A more complete description of these calculations is given in Appendix 1C to this chapter.

Annual sales may the best comparison factor for this report, but that is not the end of the story. For reasons stated earlier in this section, no readily available measure (normalizing factor) is completely fair to all companies. Any choice of normalizing factor will leave some facilities penalized unfairly and some unjustifiably rewarded, in the sense that apparent improvements in environmental performance can be influenced by business factors unrelated to the environmental variables. In cases where a fair ranking is essential, such as in evaluating companies for recognition in a program like the SGP, evaluators must be prepared to consider several alternative normalizing factors, and to consider which are the most appropriate in any particular situation on a case-by-case basis. For the purpose of this report, where the goal is to provide a clear picture of the industry, using annual sales as the plant size measure is the best choice because it provides the most easily understood analysis.

1.3.1.2 Process-by-process Data

In this section, we describe a tool that enables us to learn more from the whole data set than we can learn from any of the parts taken separately. It would be very useful to know how much water each plating process uses, how much sludge each process generates, and so on. Most platers do not have the time or equipment to keep separate records for each process they run. How can we put together data from many different platers to extract process-by-process information?

If we were very lucky, we would have data where the answer would be readily apparent. Suppose we had a dozen shops that did only zinc plating, another dozen that did only electroless nickel plating, and so on. We could average the gallons-per-dollar numbers for all the zinc shops, and we would have our water discharge answer for zinc. We would do the same for pounds of sludge, and all the other performance measures. Then we would do the same for nickel, using just the nickel shops.

Of course, we are never that lucky. Shops typically run a mix of processes, and can only give us data on their overall usage. But they can generally tell us what percent of sales is due to what process. That information can give us enough data from which to estimate resource usage for each process separately.

Again, we need some luck. If every shop ran exactly the same mix of processes (say 75% zinc and 25% nickel), we would not learn more by just putting their data together. But suppose we had one set of shops that was mostly zinc and another set that was mostly nickel. We could then see if water usage was significantly different between the two sets. For example, we might find that the average water usage for the shops that run mostly zinc is four gallons per dollar of sales, while the average for the mostly nickel shops is two gallons per dollar. That would tell us that zinc plating almost certainly consumes more water on average than nickel plating, even though we do not have data for either of the processes separately.

Now suppose we have data from many shops covering a whole range of process mix ratios, from mostly nickel, through half-and-half, to mostly zinc. Since zinc plating uses more water than nickel, we would expect the amount of water used by any shop to be greater in proportion to the percent of zinc plating that it does. We can plot the actual water usage against the percent of zinc plating for all the shops in our data set. If water usage were exactly proportional, the points indicating water usage for each shop would lie on a straight line, starting from the usage rate for an all-nickel shop (at 0% zinc), and rising to the rate for an all-zinc shop (at 100% zinc). In reality, the actual values will be scattered around the line, with more efficient shops lying below the line (using less water than expected), and less efficient shops above it, as shown in Figure 1-1.

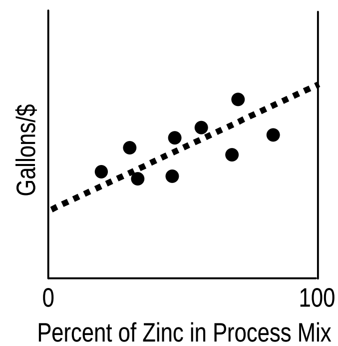

Figure 1-1. Illustration of Best Line Through Typical Data

Now suppose the only data we have are the usage rate and product mix for each shop. At the beginning of our analysis, we do not know where the line should be; we only have the scattering of points. But we can use a statistical technique to draw the “best possible” line—the line that comes as “close” as possible to all of the points. (We actually minimize the square of the distances.) That line tells us the process-by-process information we want to know. When we extend the line back to 0% zinc, it tells us the expected water usage rate for the nickel process alone. When we extend the line to 100% zinc, it tells us the expected usage rate for the zinc process alone. Thus, by drawing the best possible line, we have taken data from shops running various mixtures of the two processes, and deduced the expected water usage rates for each process separately.

That is the basic idea that we use with the more complicated data from the survey. We are dealing with 31 processes instead of two, but the principle is the same. (As it turns out, we have sufficient data to make good estimates for the six most common processes.) The model that we use is detailed in Appendix 1C to this chapter. For more information, readers may consult any standard textbook on statistical methods. The technique we are using is called *linear regression* in the literature.

1.3.2 Regression Results: Environmental Performance Versus Process Type

This section summarizes the results of the regression analysis applied to the survey data. We present resource usage and waste generation rates for the six most common metal finishing processes in our data, namely:

1. Zinc Plating
2. Nickel Plating
3. Decorative Chromium Plating
4. Electroless Nickel Plating
5. Anodizing
6. Hard Chromium Plating.

The environmental (resource and waste) performance measures that we considered are:

- Water used
- Total sludge generated
- Hazardous sludge sent to landfills
- Electricity used
- Total energy used (power and heat)
- Organic chemicals emitted.

For four of the environmental variables, we were able to obtain statistically significant results, with different processes having significantly different values. For the last two, the usage rates did not differ significantly from one process to another.

A shop's environmental performance can differ from that of other shops for many reasons, and process mix is only one of them. We can compute a quantity denoted R^2 for each environmental variable that measures how much of the shop-to-shop variation in that variable can be accounted for by considering only the shop's process mix. The value of R^2 computed from our data is given for each of the variables.

One final piece of data is included in each of the following sections. All of the regression values reported here are, of course, estimates from the available data. A certain amount of error is expected. Thus, for example, the water usage data appear to show that decorative chromium plating uses slightly more water than nickel plating. However, the numbers are close together enough that the difference is smaller than the expected error in the numbers. The apparent difference would not be considered statistically significant. On the other hand, there is a much greater difference between either of those rates and the rate for zinc plating. In this case, the difference is larger than the expected error—the higher water use rate for zinc *is* statistically significant. We use asterisks in the tables presented below to indicate when the values for a given process are considered to have a statistically significant difference from the value for zinc plating.

1.3.2.1 Water Discharged

Table 1-9 shows the results of the regression analysis applied to water discharge. Zinc plating is clearly the highest user of water among all the plating processes reported. Hard chrome plating uses the least water (many hard chrome platers in fact are able to run zero discharge, closed-loop systems). The other four processes use an intermediate amount of water.

1.3.2.2 Sludge Generated

Sludge generation provided the one case in which distinctions between zinc barrel plating and zinc rack plating were statistically significant. Thus (in this case only), we consider zinc-barrel and zinc-rack as separate processes.

Table 1-9. Water Discharge Rates by Process Type*

Process	Average Water Discharged, gal/$ sales
Zinc Plating	4.79
Nickel Plating	1.99**
Decorative Chromium Plating	2.27**
Electroless Nickel Plating	1.42**
Anodizing	1.96**
Hard Chromium Plating	0.2**

* Percent of overall variance in gallons discharged per dollar of sales accounted for by process mix: 28% (R^2 = 0.28).

** Indicates statistically significant difference from zinc plating, at 10% significance level.

Table 1-10 provides the results. Zinc barrel plating generates the most sludge on a per dollar basis—almost 3.5 times the rate for zinc rack plating, and 9 times the rate for hard chromium plating. The values given for sludge are considered on a dry weight basis. In other words, a pound of sludge with 50% water content by weight is considered to be one-half pound of sludge "as if dry."

1.3.2.3 Hazardous Sludge Land-Disposed

The difference between this variable and "sludge generated" is that this measure does not include sludge sent off-site for recycling. Some sites manage to send all of their sludge to recyclers, and therefore report zero sludge land-disposed. These companies have been omitted from the averages reported in Table 1-11.

Considering just those who do not report zero sludge land-disposed, zinc plating is associated with the highest disposal rates. The amount of sludge expected from zinc plating is roughly 4 times the amount from decorative chromium plating, and 10 times the amount from hard chromium plating.

1.3.2.4 Electricity Use

As shown in Table 1-12, hard chromium plating is the most electricity-intensive process, followed closely by zinc plating.

Table 1-10. Sludge Generation Rate by Process Type*

Process	Average (as if dry) Sludge Generated, lb/$ sales
Zinc Plating – Barrel	0.0542
Zinc Plating – Rack	0.0164**
Nickel Plating	0.00658**
Decorative Chromium Plating	0.00824**
Electroless Nickel Plating	0.00469**
Anodizing	-0.01548**
Hard Chromium Plating	0.00601**

* Percent of overall variance in pounds of sludge (as if dry) discharged per dollar of sales accounted for by process mix: 37% (R^2 = 0.37).

** Indicates statistically significant difference from zinc barrel plating, at 10% significance level.

Table 1-11. Hazardous Wastewater Treatment Sludge Land-Disposed by Process Type*

Process	Average (as if dry) Hazardous Sludge Land-Disposed**, lb/$ sales
Zinc Plating	0.0245
Nickel Plating	0.0015
Decorative Chromium Plating	0.0053***
Electroless Nickel Plating	0.0113
Anodizing	0.0186
Hard Chromium Plating	0.0021***

* Percent of overall variance in pounds of hazardous sludge (as if dry) land-disposed per dollar of sales accounted for by process mix: 21% (R^2 = 0.21).

** Includes only plants with non-zero hazardous sludge.

*** Indicates statistically significant difference from zinc plating, at 10% significance level.

Table 1-12. Electricity Use by Process Type*

Process	Average Electricity Use, kWh/$ sales
Zinc Plating	0.514
Nickel Plating	0.453
Decorative Chromium Plating	0.458
Electroless Nickel Plating	0.153**
Anodizing	0.485
Hard Chromium Plating	0.536

* Percent of overall variance in electricity used per dollar of sales accounted for by process mix: 23% (R^2 = 0.23).

** Indicates statistically significant difference from zinc plating, at 10% significance level.

Not surprisingly, electroless nickel plating uses only about a fourth as much electricity per dollar of sales. In general, the results we derived using regression analysis are consistent with what common sense would lead us to expect, which reinforces our level of confidence in this analysis.

1.3.2.5 Total Energy Use

There are no statistically significant process differences in total energy consumption per dollar of sales. As shown in Table 1-13, the underlying "noise" drowns out any process effects.

In addition, another statistical measure, the F-statistic, was highly insignificant, meaning that we have no basis to conclude that process distinctions have any correlation with our data on Btu per dollar of sales. This "non-result" may be the result of poor-quality data (that is, incomplete reporting on "other fuels" besides electricity). It may also be difficult to untangle fuel used for process heat from fuel used for space heating; otherwise, we would see at least some significance.

1.3.2.6 Organic Chemical Emissions

As with total energy use, there are no statistically significant process differences in reported chemical emissions rates, as indicated in Table 1-14.

As with total energy use, the F-statistic was highly insignificant, so we have no reason to believe that process type is at all correlated with the organic chemical emissions data. Again, this may reflect more on data quality than on true emissions patterns. Shops may not be keeping accurate records of solvent use, for example.

*Table 1-13. Energy Use by Process Type**

Process	Average Total Energy Use, (Btu/$ sales)
Zinc Plating	6,306
Nickel Plating	6,967
Decorative Chromium Plating	7,115
Electroless Nickel Plating	1,300
Anodizing	4,020
Hard Chromium Plating	4,649

* Percent of overall variance in total energy used per dollar of sales accounted for by process mix: 8% ($R^2 = 0.08$).

*Table 1-14. Organic Chemical Emissions by Process Type**

Process	Average Organic Chemical Emissions, lb/$ sales
Zinc Plating	0.00269
Nickel Plating	0.00153
Decorative Chromium Plating	0.00206
Electroless Nickel Plating	0.00155
Anodizing	0.000588
Hard Chromium Plating	0.00193

* Percent of overall variance in total energy used per dollar of sales accounted for by process mix: 14% ($R^2 = 0.14$).

1.3.3 Regression Results: Environmental Performance Versus Other Company Characteristics

In Section 1.3.2, we considered how six environmental performance measures (resource usage and waste generation) were related to different metal finishing processes. In this section, we look at the same six performance measures and see how they are related to company characteristics other than the processes these companies carry out.

In all cases, we examine only one characteristic at a time. That is, even though we already know that the amount of water a plant discharges will depend on what processes the plant runs, we will temporarily ignore this fact. For example, when we consider whether a plant's repetitive or non-repetitive work affects its water discharge rate, we do not try to take its process mix into account. We look only at the effect of the characteristics we are studying.

1.3.3.1 Repetitive Versus Non-Repetitive Work

Survey participants were asked to describe the percent of their sales they consider to be repetitive work (see Section 1.2.5.3 for definitions of repetitive and non-repetitive work). The results are summarized in Table 1-15. The extent to which a company considers its business to be repetitive versus non-repetitive appears unrelated to most environmental performance measures. The one exception is sludge generation, where sludge rates are almost seven times higher for repetitive than for non-repetitive operations.

1.3.3.2 Rack Versus Barrel Plating

We also asked plants to provide data on the extent to which their parts are transported via racks, barrels, or "other" mode, for all the processes they carry out. We then looked for any significant differences in environmental performance between rack and barrel processing. As shown in Table 1-16, barrel plating generates significantly more waste and water discharge than does rack plating.

Table 1-15. Environmental Performance by Repetitive vs. Non-Repetitive Work

Performance Measure	Repetitive Work	Non-Repetitive Work
Water Discharged, gal/$ sales	2.97	2.25
Sludge Generated, lb/$ sales	0.0246	0.00361*
Hazardous Sludge Land-Disposed, lb/$ sales	0.0168	0.00897
Organic Chemical Emissions, lb/$ sales	0.00177	0.00105
Electricity Use, kWh/$ sales	0.399	0.404
Total Energy Use, Btu/$ sales	4200	5989

* Indicates statistically significant difference between repetitive and non-repetitive.

Table 1-16. Environmental Performance by Barrel vs. Rack Transport Mode

Performance Metric	Rack	Barrel
Water Discharged, gal/$ sales	2.21	4.83*
Sludge Generated, lb/$ sales	0.00875	0.048*
Hazardous Sludge Land-Disposed, lb/$ sales	0.0108	0.0251*
Organic Chemical Emissions, lb/$ sales	0.0013	0.00234
Electricity Use, kWh/$ sales	0.395	0.398
Total Energy Use, Btu/$ sales	5265	4332

* Indicates statistically significant difference between between rack and barrel.

Note that this result refers to all types of metal finishing processes. In Section 1.3.2.2, we had turned the question around and asked whether rack versus barrel made any difference for any single process. In that case, the only significant difference we saw was for zinc barrel plating, which generated more sludge than rack plating.

1.3.3.3 Regulatory Constraints

Different plants fall under different regulatory requirements. There are two main categories under federal regulations, and many plants are governed by state or local regulations that are more stringent than federal regulations.

When we looked at the data, we found that the regulatory requirements faced by a plant are generally not significant predictors of their environmental performance (see Table 1-17). For reasons that are not entirely clear, plants reporting that they must comply with a combination of CFR 413 *and* CFR 433 have significantly *higher* rates of sludge generation and organics emissions.

1.3.3.4 Participants in Strategic Goals Program Versus Non-participants

We wanted to see whether we could find any statistically significant differences between shops that had chosen to participate in the Strategic Goals Program and other such efforts. We could not. Participation in the SGP had no statistical relationship to a shop's environmental performance on any of the six environmental performance measures, as shown in Table 1-18. We even tried taking the process mix of each shop into account; there was still no difference.

As noted in Section 1.2.4.2, this means that the SGP has been successful in attracting a true cross section of platers. According to independent SGP data (not related to this survey) over the first three years of the program, the SGP participants have shown steady improvement from year to year.

Table 1-17. Environmental Performance by Regulatory Requirements

Performance Metric	CFR			Regulation	
	413	433	413 & 433	Local	Other
Water Discharged, gal/$ sales	2.99	1.4	1.59	2.02	0.35
Sludge Generated, lb/$ sales	0.01645	0.0128	0.03461*	0.0074	0.0138
Hazardous Sludge Land-Disposed, lb/$ sales	0.01414	0.0036	0.0217	0.0107	0.00754
Organic Chemical Emissions, lb/$ sales	0.00139	0.000442	0.00351*	0.000478	0.000373
Electricity Use, kWh/$ sales	0.306	0.274	0.388	0.313	0.407
Total Energy Use, Btu/$ sales	4590	1470	3050	3362	1573

* Indicates significant difference from CFR 413.

Table 1-18. Environmental Performance by SGP Participation Status

Performance Metric	SGP	Non-SGP
Water Discharged, gal/$ sales	2.964	2.809
Sludge Generated, lb/$ sales	0.01978	0.01860
Hazardous Sludge Land-Disposed, lb/$ sales	0.0166	0.01342
Organic Chemical Emissions, lb/$ sales	0.00121	0.00170
Electricity Use, kWh/$ sales	0.4212	0.3850
Total Energy Use, Btu/$ sales	5120	4418

* Indicates statistically significant difference between repetitive and non-repetitive.

1.3.4 Adjustment Formulas

The goal of this section is to find a way to predict the resource usage and waste generation that we would expect from a shop, assuming that we know various characteristics of the shop, such as process mix, plating methods used, and various business factors. When we look at the actual performance of a real shop with these same characteristics, we can compare the expected and the actual values and determine how much better or worse the shop is doing than expected.

We will find an *adjustment formula* for each performance measure. We can substitute the numbers representing a company's characteristics into the formula and calculate the expected value for the company's performance on that metric. It is a simple formula—we are given a set of coefficients, one for each characteristic. We multiply each characteristic times the corresponding coefficient, and add them all together.

For example, suppose we want to calculate how much electricity we would expect Shop A to consume if it runs 25% nickel and 75% zinc, and is located in the Northeast. (Process mix and location turn out to be the variables that are most significant in predicting electricity use.) We would use three coefficients:

1. c_1 relating nickel to power consumption
2. c_2 relating zinc to power consumption
3. c_3 relating geographical location to power consumption.

The adjustment formula for electricity also contains a constant term, c_0.

We put these coefficients together with the data for Shop A to calculate our prediction. In this case, we use 0.25 for Shop A's nickel operation (its share of the sales dollar), 0.75 for zinc, and 1 for location (all its operations are in the Northeast). Our formula is therefore:

kWh electricity used per dollar of sales = $c_0 + c_1 (0.25) + c_2 (0.75) + c_3 (1)$

(The actual values for the coefficients are given below in Section 1.3.4.3, Table 1-22.) Substituting the actual values in the formula (using approximate values for illustration), we find:

$0.74 - (0.076 \times 0.25) - (0.012 \times 0.75) - 0.24 =$ 0.472 kWh/$ sales

We can compare this result with the process-by-process breakdown of average electricity usage per sales dollar given in Table 1-12 and verify that it is reasonable.

We could have used different ways to measure Shop A's characteristics; labor hours instead of sales dollars, for example. We could still use them in an adjustment formula of this type, with a different set of coefficients. We use sales dollars because, as discussed in Section 1.3.1.1, it gives us the best prediction with the data that we have.

But what if we have not isolated all the relevant characteristics? Suppose, for example, left-handed shop owners consistently performed better (or worse) than their right-handed competitors. Assuming we had the data on shop owners' "handedness," we could add that variable to the adjustment formula, revising all the other coefficients to take it into account. We would still come up with reasonable predictions, and they would be entirely consistent with the data. In the unlikely event that left-handedness really was significant, the revised formulas would, in fact, be better predictors.

There may very well be variables in our data that we could have taken into account but were not clever enough to see. If the alert reader can find some distinguishing feature in the data that systematically separates better and worse environmental performers, then he or she can improve the formulas. The potential for improvement does not mean that the formulas given here are "wrong." Predictions based on our formulas would still be reasonable, but they would not be as good as the reader's improved formulas, in the sense that the reader's formulas applied to shops in the data set will generally give results closer to the actual reported performance.

However, if we want to apply these formulas appropriately to shops that are *not* a part of the data set, we have to make the further assumption that our data are representative of the industry as a whole. For example, it could have happened by chance that the left-handed platers who chose to respond to our survey all ran particularly clean operations. An adjustment formula that included handedness would work very well for the shops in the data set, but would not work well in the real world. The fact that we have 132 shops in the data set makes it enormously unlikely that we would find statistically significant differences between left- and right-handed platers. But, if enough different characteristics are examined, we may well, by chance, find some characteristic that does appear to make a difference in our sample, but would not be significant in the population as a whole. Subtle effects due to selection bias can never be completely ruled out.

Thus, when characteristics are chosen for use in the adjustment formulas, we need to apply an element of common sense. It would, for example, be misleading to comb the data set for any and all variables that happen to be related to good performance and to use them in the formulas. That is almost guaranteed to pick out whatever selection bias there is, and to produce formulas that work well for the data set and badly for the rest of the world.

The shop characteristics we have chosen to use in the adjustment formulas are few, and are plausibly related to the real world. However, the reader should be aware that they represent choices and are not dictated uniquely by the data.

In Chapter 2, we will use the adjustment formulas developed in this section to rate our survey participants, and to discover which companies represent the "best performers." By this term, we mean those best at using less resources and generating less waste than we would expect from shops with their characteristics.

Companies can also use the adjustment formulas to evaluate their own performance. They can use their own characteristics in the formulas and determine what level of resource usage and waste generation would be expected for a plant like theirs. They can then compare their actual with their expected performance. Activities such as the Strategic Goals Program can also use this framework for evaluating their participants for recognition. Note that when the adjustment formulas are used in this way, the remarks above should be kept in mind.

1.3.4.1 "Best" Regression Results

First, we need to decide which environmental performance measures we are going to try to predict with adjustment formulas. Then, we need to decide which shop characteristics we will use for each measure to make the prediction.

Three out of the six performance measures look like good candidates for the criteria that we will want to use to select the "best performers" from among the survey participants. They are:

- Water used
- Total sludge generated
- Electricity used.

But what about the other three—total energy used, organic chemicals emitted, and hazardous sludge sent to landfills?

As we saw in Sections 1.3.2.5 and 1.3.2.6, total energy use and organic chemical emissions gave us the least satisfactory statistical results. There did not seem to be any obvious way to use process mix to account for these measures, even though we might expect the measures to be different for different processes. It could be that the data we had were incomplete or confusing. In any case, we will not be able to rely on these measures to help us select possible best practices companies. We will nevertheless use organic chemical emissions on the simple principle that "less is better." However, we will not need an adjustment formula to use the data in this way.

The information on hazardous sludge sent to landfills is not useful for finding top performers, but for a reason unrelated to the quality of the data. According to survey results, roughly half of the survey participants reported zero sludge land-disposed. This number is sufficiently high that we really have to consider a zero value to be a prerequisite for being a top performer. If so, analyzing the variation among those companies with non-zero values is irrelevant.

Therefore, we will develop adjustment formulas only for water discharged, sludge generated, and electricity used per dollar of sales. Each of these performance measures is treated separately below. For each, we will describe the shop characteristics that we feel are most relevant for predicting these measures, and we will present the coefficients to be used in the adjustment formulas for calculating the prediction.

1.3.4.2 Best Adjustment Formula: Water Discharged

We already know that a plant's process mix is a good predictor of the water it will discharge per sales dollar. Could we usefully take into account any other plant characteristics?

When we examined other factors individually, the rack versus barrel distinction also looked significant. But, when we add this distinction into a regression model that already includes process mix, its significance disappears. Therefore, using the rack versus barrel distinction in the adjustment formula would not add any value.

In fact, it appears that the best we can do is what we have done already—use only process mix. But, we will find it useful to go one step further than we went in Table 1-9 (see Section 1.3.2.1), and include other processes combined into meaningful categories. Our goal there was to estimate the amount of water used for each process individually. For the less-common plating processes, we did not have enough data to produce a meaningful result specific to each process. Here, our goal is to predict water usage from a shop's characteristics. If we know that a shop does a lot of silver plating, for example, we should be able to use that fact to improve our prediction.

Therefore, we took the 25 less-common metal finishing processes in our data set and grouped them into five categories:

1. Precious metals plating
2. Silver plating
3. Other plating: cadmium, tin, copper, brass, bronze, tin–lead, and iron
4. Other coating: phosphating, passivation, chromating, black oxide, anodizing (chromic acid), mass finishing, chemical milling, derusting, vacuum coating, and "other 2"
5. Painting, electropolishing, powder coating, hot solder dip (molten), paint stripping, and undesignated "other."

Results for these five additional categories were virtually never statistically significant, and we have not included them in the process-by-process tables, even as overall categories. But we kept them in the model, rather than simply collapsing them all into one huge "other" category, because we felt the distinctions were meaningful. Including them in the adjustment formulas may help us make better predictions.

Table 1-19 presents the complete results for the water discharge rate regression analysis. As in the example in Section 1.3.4, computing a company's "expected" or "predicted" value, based on its process mix, is straightforward. Take the share of sales* (fraction of a sales dollar) accounted for by each of the process categories listed in Table 1-19. (The fractions must sum to 1.) Multiply each share by the corresponding coefficient listed in Table 1-19, and sum across all 11 process categories.) The result is the company's predicted water discharge value, in gallons per dollar of sales.

* The share of sales from each process is listed in Appendix 1B, Table 1B-1, for each company in the database.

Table 1-19. Regression Coefficients for Estimating Predicted Values, Gallons of Water Discharged per Dollar of Sales (R^2 = 28%)

Variable, Sales Fraction	Estimated Coefficient
Zinc Plating	4.79
Nickel Plating	1.99*
Decorative Chromium Plating	2.27*
Electroless Nickel Plating	1.42*
Anodizing	1.96*
Hard Chromium Plating	0.20*
Precious Metals Plating	4.06
Silver Plating	-0.05*
Other Plating	1.80*
Other Coating	4.07
Paint, Powder Coat, Polishing, Undefined Other	2.36

* Indicates statistically significant difference from zinc plating, at 10% significance level.

An example of the use of these coefficients to calculate the expected discharge for the actual process mix reported by one of the companies in the survey data may be found in Chapter 2, Section 2.1.1, Table 2-1).

Since process mix was the only plant characteristic chosen for water discharge, it is easy to see that the coefficients for the first six processes are identical to the process-by-process "average water discharged" numbers given in Table 1-9. If one process accounted for all the plant's operations, its sales fraction would be one, and all the rest of the processes would have a sales fraction of zero. The "gallons per dollar of sales" prediction would have to equal the coefficient for the plant's process. Conversely, if other shop characteristics besides process mix were adding terms to the equation, as we see in the next case, the coefficient would have to be different.

1.3.4.3 Best Adjustment Formula: Sludge Generated

Table 1-20 lists the regression coefficients for predicting the sludge generation rate.

Table 1-20. Regression Coefficients for Estimating Predicted Values, Pounds of Sludge Generated per Dollar of Sales (R^2 = 41%)

Variable	Estimated Coefficient
Constant Term*	0.02818
Zinc Barrel Plating	0
Zinc Rack Plating	-0.01612
Zinc “Other” Plating (Neither Rack nor Barrel)	-0.02164
Anodizing	-0.04061**
Nickel Plating	-0.02510
Decorative Chromium Plating	-0.02315
Electroless Nickel Plating	-0.02981
Hard Chromium Plating	-0.02529
Precious Metals Plating	-0.03014
Silver Plating	-0.02117
Other Plating	-0.02314
Other Coating	0.05071**
Paint, Powder Coat, Polishing, Undefined Other	-0.01623
Share of Sales to the Automotive Market	0.01725**
Share of sales to Fasteners Market	0.03705**

* The constant term represents the predicted value for plants that are 100% zinc-barrel plating, with 0 sales to the automotive or fastener markets.

** Statistically different from zinc barrel plating, with 0 sales to auto or to fasteners, at 10% significance level.

As with the previous adjustment formula, a plant’s process mix is a good predictor for the amount of sludge it generates. For the case of sludge, maintaining the distinction between rack and barrel plating for zinc gives better results. In addition, we found that the market that a plant serves is also a significant piece of information. Suppliers to the automotive market, and those who plate fasteners, generated significantly more sludge per sales dollar than did metal finishers serving other markets.

The reason for this finding is not relevant to the mathematics, but it is worth noting that the observed difference in performance might have nothing to do with the environmental priorities of companies serving those markets. The reason may simply be a reflection of the fact that suppliers to those two market segments do not generate as many sales dollars for a given amount of material plated as do their counterparts serving other customers. The appearance of customer type in the adjustment formula stems from the fact that we have chosen sales dollars as our basic plant size comparison factor. Had we chosen a different variable, a different set of metal finishing companies might have found themselves honored with the “distinction” of generating more sludge.

In practical terms, it is only fair to single out suppliers to the automotive market and those who plate fasteners by including them in the adjustment formula. Otherwise, plants in this category would find themselves unfairly penalized for supplying customers who can command lower prices.

1.3.4.4 Best Adjustment Formula: Electricity Consumption

Again, process mix is a good predictor of electricity use. But we also find that a shop’s geographic location has an important influence on electricity consumption. We have, therefore, included regional variables in our preferred adjustment formula.

First, we divided all of the states into regions, as shown in Table 1-21. The division is somewhat arbitrary, but refinements are not likely to improve prediction significantly. Not all states were assigned to a region, since not all states were represented among survey participants.

Table 1-21. Definitions of Regional Categories

Region	States Included
Northeast—Great Lakes	Connecticut, Illinois, Indiana, Massachusetts, Michigan, Minnesota, New Jersey, New York, North Dakota, Ohio, Pennsylvania, Rhode Island, Vermont, Wisconsin
Mid-Plains and Mountain	Arkansas, Colorado, Kansas, Missouri, Nebraska, Oklahoma, Utah
Mid-Atlantic and South	Alabama, Georgia, Maryland, Mississippi, South Carolina, Texas, Virginia
Southern CA	California with zip code < 94000
Northwest	California with zip code ≥ 94000; Oregon, Washington

To use a plant's region in the adjustment formula, assign the plant a value of 1 for the region in which it is located, and a value of 0 for all other regions. In other words, the coefficient associated with the plant's region adds full-strength to the prediction, while all the other regional coefficients are zeroed out.

Table 1-22 presents the complete set of regression coefficients that can be used for calculating each plant's predicted value of kilowatt–hours per dollar of sales.

In Chapter 2, we use the results and the regression "machinery" developed in this chapter to rank the survey respondents, and to identify those companies whose environmental performance is worth emulating.

Table 1-22. Regression Coefficients for Estimating Predicted Values, Kilowatt–hour Consumption per Dollar of Sales (R^2 = 33%)

Variable	Estimated Coefficient
Constant Term*	0.74194
Zinc Plating	-0.01208
Anodizing	0.00648
Nickel Plating	-0.07561
Decorative Chromium Plating	-0.01948
Electroless Nickel Plating	-0.29875**
Hard Chromium Plating	0
Precious Metals Plating	-0.34046
Silver Plating	-0.43414
Other Plating	-0.28610**
Other Coating	-0.28901
Paint, Powder Coat, Polishing, Undefined Other	-0.31432**
Northeast—Great Lakes	-0.24275**
Mid-Atlantic and South	0
Mid-Plains and Mountain	-0.13522
Southern CA	-0.30629**
Northwest	-0.36258**

* In this case, the formula includes a constant term, which changes the interpretation of the coefficients. The constant term now represents what we would expect for a plant that is 100% Hard Chromium Plating and located in the Mid-Atlantic/South region. (There is nothing special about this process or region—it simply represents the most convenient baseline.) All other coefficients represent the expected difference between this default group and other processes or regions. The method for calculating predicted values is the same: take the plant's own value for each variable on the left, multiply by the coefficient on the right, and then sum these products. The constant term is present, unmodified, in the formula for every plant. (An example was presented in Section 1.3.4.)

** Statistically different from Hard Chromium Plating, Mid-Atlantic/South, at 10% significance level.

Appendix 1A: Phase 1 and Phase 2 Survey Forms

Metal Finishing Industry Benchmarking Survey

Endorsed by: American Electroplaters and Surface Finishers Society
National Association of Metal Finishers
Metal Finishing Suppliers' Association

Instructions

1. The National Metal Finishing Resource Center (NMFRC), which is operated by the National Center for Manufacturing Sciences (NCMS) is conducting this benchmarking survey and is responsible for all aspects of data collection and management. All information and data contained in this survey form will be kept confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form. If you have any questions or concerns with respect to confidentiality, contact Dr. Paul Chalmer of NCMS at 734-995-4911 (email: paulc@ncms.org).
2. The identification of your firm is very important to the success of the survey, since NMFRC staff may need to recontact firms for clarification and verification of responses. However, we will accept and use anonymous responses. Therefore, if our procedures for confidentiality are not sufficient for your firm, then skip any questions that may identify your firm.
3. Please complete all applicable sections of the survey form. Some questions request specific data, such as costs or quantities of waste. If exact data are not available, use estimates based on your knowledge of the process.
4. If your responses do not fit into the spaces provided on the survey form, please use ordinary paper and clearly indicate which question the response applies to. Please print clearly or type.
5. An example of a completed Benchmarking Survey form is included in your survey package. This form is intended to help you understand what information is being requested and the anticipated format of the response.
6. If you have any questions, please contact George Cushnie at 703-264-0039 (email: geoc@NMFRC.org).

All information and data contained in this survey form are confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form.

Return the completed form to:
National Metal Finishing Resource Center
Technical Offices
3433 Valewood Drive
Oakton, VA 22124
Phone: 703-264-0039
Email: Benchmarking@NMFRC.org

Metal Finishing Industry Benchmarking Survey

1. Background information

This information will be used to contact you for clarification, if necessary, and at the completion of the project to provide you with a summary of the Benchmarking results.

Your Name: ______________________ Title: ______________________

Facility Name: ______________________

Phone: ____________ Fax: ____________ E-mail: ____________

Street Address: ______________________

City/State/Zip: ______________________

2. Water purchased/wastewater discharged

This information will be used along with other data to evaluate differences in water use among metal finishing companies.

Volume of water purchased during 1998: ____________ gal/year

Volume of metal finishing wastewater discharged during 1998: ____________ gal/year

3. Which wastewater regulations applied to your facility during 1998 for metals and cyanide?

This information will be used to evaluate and compare different discharge conditions and restrictions.

- ☐ Electroplating (40 CFR 413)
- ☐ Metal Finishing (40 CFR 433)
- ☐ Combination of 413 and 433 standards
- ☐ Local standards that are more stringent (for at least one parameter) than the Electroplating and Metal Finishing standards
- ☐ Other: ____________
- ☐ Not sure

4. Wastewater treatment sludge data

The data collected by this question will be compared to other data in the survey to evaluate differences in sludge production among metal finishing processes and the extent to which sludge is being recycled.

Total amount of wastewater treatment sludge generated during 1998: ____________ lbs/year

Amount of hazardous wastewater treatment sludge generated during 1998 that is shipped off-site for land disposal*: ____________ lbs/year

Average water content of wastewater treatment sludge**: ____________ % by weight

**If your wastewater treatment sludge was delisted or it was sent off-site for metals recovery rather than disposal, enter zero.*

***If water content is unknown, indicate dewatering technology used:* ☐ *Filter Press* ☐ *Sludge Dryer* ☐ *Other (indicate):* ____________

5. Organic chemical emissions to air and water

Record any organic chemicals found on the TRI list that are used at your facility and indicate the quantity of these chemicals that are released to the air and water. Common TRI organic chemicals used by metal finishing companies include: trichloroethylene (TCE), toluene, methyl ethyl ketone (MEK), formaldehyde, methanol, isopropyl alcohol, n-butyl alcohol, thiourea, glycol ether, and xylene.*

Chemical name	Quantity of the chemical released to air + water (lbs/year)
1. ____________	____________
2. ____________	____________
3. ____________	____________

If more space is needed, use the space below or attach additional pages.

**This is not an exhaustive list of TRI organic chemicals. A complete list can be found at: www.epa.gov/opptintr/tri/report.htm*

6. Wastewater Treatment Processes

Check the boxes for the systems that best describe your treatment methods during 1998 for metals and cyanide.

Cyanide Destruction

☐ None

☐ Alkaline chlorination: (☐ Batch ☐ Continuous)

☐ Other:____

Chromium Reduction

☐ None

☐ Chromium reduction using sulfur dioxide, sodium bisulfite, or sodium metabisulfite: (☐ Batch ☐ Continuous)

☐ Other:____

Metals Removal

☐ None

☐ Conventional hydroxide precipitation using a clarifier for solids removal: (☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation using a membrane filtration for solids removal: (☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation, plus end-of-pipe ion exchange polishing: (☐ Batch ☐ Continuous)

☐ Conventional hydroxide precipitation, plus granular bed filtration polishing: (☐ Batch ☐ Continuous)

☐ Ion exchange

☐ Other:____

7. Energy data use (1998)

Many metal finishing companies can reduce operating costs by lowering energy use. The data collected by this question will help establish a benchmark for different segments of this industry so that companies can evaluate their own usage rates and possibly lower their operating costs in the future.

Electricity consumed: ______________ kWh/year Natural gas consumed: ______________ therms/year*

Fuel oil/other (specify type, units): ______________

**Report whatever units are convenient (e.g., therms, ccf, BTUs)*

8. Production Data

The data collected by this question will be used to "normalize" your data so that it can be meaningfully compared with data from other facilities.

For facilities that track the following, provide value(s) for 1998 (provide as many possible):

Surface Square Feet Processed (ssf): ______________

Total number of labor hours for all people working in the metal finishing shop: ______________

Rectifier amp-hours: ______________

Metal finishing sales: $______________

Total amount spent on purchases* of raw materials for metal finishing (e.g., metals and chemicals): $______________

Total amount spent on purchased services (e.g., any subcontracting, such as heat treating, shipping or consulting): $____________

Total amount spent on utilities (electricity, oil, gas, water, etc.): $______________

**Purchases should NOT include any spending on payroll (even if done by contract workers), insurance, health care, workman's comp, training, rent, interest, depreciation, or capital costs.*

9. What percentage of your 1998 metal finishing sales was derived from the following business areas (responses should total 100%)?
The data collected by this question will be used along with other survey data to identify differences in water use and other factors among metal finishing business areas.

_____% Motor Vehicles	_____% Aerospace/Aircraft	_____% Railroad
_____% Building/Construction	_____% Wire Goods and Pipes	_____% Plumbing Fixtures
_____% Sporting Goods/Toys	_____% Military/Govt.	_____% Printed Wiring Boards
_____% Other Electronics	_____% Jewelry/Watches	_____% Medical
_____% Furniture	_____% Machinery/Industrial	_____% Boats/Ships
_____% Household Appliances	_____% Other Household Items	_____% Hardware/Tools
_____% Fasteners	_____% Other (indicate: ______________________)	

10. Some metal finishing shops process different types of parts every day and must account for this by frequently making changes to their production methods. Other shops process nearly identical parts day after day, even though the workload may come from different clients, and don't need to change their processing methods. What percentage of your 1998 metal finishing sales was from repetitive work and what percentage was from non-repeating work (the total of these two responses should equal 100%):

_____% of metal finishing sales was from repetitive work

_____% of metal finishing sales was from non-repeating work

11. Metal finishing (MF) process data for 1998
This question is a key element of the survey. The data collected by this question will be used with data from most other sections of the survey to identify differences in water use, sludge generation, energy use, etc., between the various processes employed by the metal finishing industry.

	In the three columns below indicate the approximate percentages contributed by each process. Each column should add up to 100%				Percentage of MF work performed with each process that is transported using racks, barrels, or other. See instructions below.		
Process*	Percentage of metal finishing sales, %	Percentage of MF shop labor labor-hours, %	Percentage of surface area processed, %	Percentage of rectifier amp-hrs, %	% Rack	% Barrel	% Other**
TOTAL	100%	100%	100%	100%			

**List general processes only. For example, if you operate a decorative Cu-Ni-Cr line, do not list cleaning, Cu plating, Ni plating, etc. Simply list decorative chromium. The following list is intended to help select process names.*

<u>Electroplating</u>
Brass
Cadmium
Chromium, decorative (includes Cu, Ni layers)
Chromium, hard
Copper
Gold
Iron
Nickel, decorative
Nickel, industrial
Silver, decorative
Silver, industrial
Zinc

<u>Other Surface Finishing</u>
Anodizing, chromic acid
Anodizing, sulfuric
Black Oxide
Bright dipping
Chem milling
Chromating
Electroforming
Electropolish
Mass finishing
Mechanical plating
Nickel, Electroless
Painting
Passivation
Phosphating
Powder coating
PWB manufacturing (includes all PWB processes)

***Indicate type.*

End of survey. Thank you for your time.

Metal Finishing Industry Benchmarking Survey

Phase II

Endorsed by: American Electroplaters and Surface Finishers Society
National Association of Metal Finishers
Metal Finishing Suppliers' Association

All information and data contained in this survey form are confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form.

Return the completed form to:
National Metal Finishing Resource Center
Technical Offices
3433 Valewood Drive
Oakton, VA 22124
Phone: 703-264-0039
Email: Benchmarking@NMFRC.org

Instructions

1. The National Metal Finishing Resource Center (NMFRC), which is operated by the National Center for Manufacturing Sciences (NCMS) is conducting this benchmarking survey and is responsible for all aspects of data collection and management. All information and data contained in this survey form will be kept confidential. Any use or publication of the data will not identify the name or location of the respondent company or individual completing the form. If you have any questions or concerns with respect to confidentiality, contact Dr. Paul Chalmer of NCMS at 734-995-4911 (email: paulc@ncms.org).

2. This survey is the second phase of a two-phase benchmarking project. Only companies which responded to Phase I have received this form. For consistency, it is most desireable that the same person who completed Phase I also complete this Phase II survey. However, it is not absolutely necessary.

3. Please complete all applicable sections of the survey form. Some questions request specific data, such as costs or quantities of waste. If exact data are not available, use estimates based on your knowledge of the process.

4. If your responses do not fit into the spaces provided on the survey form, please use ordinary paper and clearly indicate which question the response applies to. Please print clearly or type.

5. If you have any questions, please contact George Cushnie at 703-264-0039 (email: geoc@NMFRC.org).

Facility Code: ______

Benchmarking Survey Form – Phase II

The purpose of this survey form is to collect detailed information that will be used to establish a metal finishing pollution control benchmark. The benchmark will help determine how the best performing facilities achieve environmental protection. The information you provide will be correlated with your Phase I responses.

1. **Company/point-of-contact** *(please change any incorrect information).*

   Facility Name: ______

   Point-of-Contact: ______

2. **Indicate which of the following management approaches apply to your facility.**
   This information will be used along with other data to determine if certain management approaches impact environmental performance.

   ☐ Employees are organized into work teams and given certain management responsibilities
   ☐ Company uses Statistical Process Control (SPC) or other statistical methods in its day-to-day quality procedures
   ☐ Engaged in Total Quality Management (TQM) or similar program
   ☐ Company is working toward or achieved ISO 9000 certification
   ☐ Company is working toward or achieved ISO 14000 certification

3. **How many hourly, metal finishing shop floor employees did you have as of the end of 1998 (12/31/98)? (Do NOT include office workers.):** ______
   Indicate below how many of those hourly shop employees (the ones you counted above) had received formal training in the following subject areas within the past 3 years (1996-98). Please include only structured training programs, such as courses and workshops. Include both programs conducted by outside trainers, and any structured training programs you conduct in-house. Do NOT include informal training that is done while workers carry out their usual day-to-day activities.

Subject Areas	Number of Hourly Shop Workers Trained During Last 3 Years
Metal finishing principles and chemistry	______
Waste treatment/regulatory compliance	______
Hazardous material handling/spill response	______
Pollution prevention	______
Hazardous waste handling	______

   Consider the total number of labor hours spent receiving this training.
   Roughly what percent of those hours were in courses developed and conducted by your own staff? ______%

4. **Facility conditions and activities**
   This information will be used to investigate potential correlations between facility housekeeping activities and environmental performance.

   On a scale of 1 to 5, indicate how well your facility is maintained for each condition described below.

   Score 1 to 5, where: 1 = Never; 2 = Sometimes; 3 = Often; 4 = Almost Always; 5 = Always

   ____ Little or no rust is visible on metal surfaces such as tanks, pipes, and equipment.
   ____ Shop floors are cleaned daily and are kept free of debris and dry except for unusual situations.
   ____ The shop is maintained in an orderly fashion and the processing area is not cluttered with materials (chemical containers) or parts.
   ____ Empty containers and packaging are immediately removed from the production area and recycled or discarded.
   ____ The metal finishing shop is maintained in a sufficiently attractive and safe condition that customers and/or the general public could be given tours at any time.
   ____ The workplace is kept free of fumes and steam (may arise from hot process tanks).
   ____ The workplace is maintained at a comfortable temperature in both the winter and summer.
   ____ Process tanks are never idle for more than 6 months. Idle tanks are drained and the solution is recycled/treated/disposed or properly stored.
   ____ Process and rinse tanks are kept free of floating oil and debris.
   ____ The worker's break room and/or locker room is kept in an orderly and clean condition.

5. **Do you have formal, written procedures or documented workplace rules covering each of the following areas? If yes, to what extent do your written procedures actually reflect the way you usually do things?**
This information will be used along with other data to determine if certain procedures impact environmental performance.

KEY
1. No written procedures.
2. Written procedures are out-of-date or inaccurate; they do not reflect our usual way of doing things.
3. Written procedures reflect our usual and preferred practice; exceptions occur, and we do not rigidly monitor conformity.
4. Written procedures reflect required practice: exceptions rarely occur and are cause for corrective action.

If not applicable, enter NA.

AREAS	ENTER NUMBER (1 TO 4), SEE KEY
Plating/finishing procedures	______
Bath quality/performance	______
Preventative maintenance	______
Waste treatment equipment operation/maintenance	______
Wastewater sampling	______
Hazardous waste management	______
Hazardous material handling/spill response	______

6. **Do you keep records for each of the following? If yes, what purpose do these records serve?**
This information will be used along with other data to determine if certain recordkeeping practices impact environmental performance.

KEY
1. No records are kept.
2. Records are kept, but typically not used for any purpose (except perhaps to meet legal requirements).
3. Records are kept. They are analyzed at least annually, but less than monthly, and used to improve performance.
4. Records are kept. They are analyzed at least monthly, and used to improve performance.

If not applicable, enter NA.

AREAS	ENTER NUMBER (1 TO 4), SEE KEY
Bath chemistry (analytical)	______
Bath chemical additions	______
Bath temperature	______
Rectifier use	______
Preventative maintenance logs	______
Rejects (misplated parts)	______
Customer returns	______
City water chemistry (e.g., hardness)	______
Units of production (number of parts, pounds, square feet, etc)	______
Electricity use	______
Water use	______
Treatment sludge generation	______
Waste treatment chemical reagent use	______

7. **Do you use any of the following energy-savings practices or technologies?**
This question will help identify which energy conservation practices are commonly used.

Conducted an energy audit .... ☐ Yes ☐ No
A facility-wide peak demand control system .... ☐ Yes ☐ No
Heat recovery system (hot water, exhaust stack) .... ☐ Yes ☐ No
Co-generation .... ☐ Yes ☐ No
Insulated hot process tanks .... ☐ Yes ☐ No

☐ Other (indicate): ______________________

8. Environmental Audit/Pollution Prevention

This information will be used to identify what procedures are used by metal finishing companies to reduce the generation of pollution and prevent chemical exposure to employees and the local community.

Check Yes if performed or updated within the past three years (1996-1998). Otherwise check No.

P2 assessment conducted:........ ☐ Yes ☐ No

If you have conducted a P2 assessment, then identify which of the following were performed:

Prepared a process map of the facility operations:........ ☐ Yes ☐ No

For each process step, identified raw material and energy inputs:........ ☐ Yes ☐ No

For each process step, identified all outputs (e.g., air emissions, wastewater, hazardous waste, product): .... ☐ Yes ☐ No

Included auxiliary operations in the process map (e.g., shipping, waste treatment):........ ☐ Yes ☐ No

Prioritized the waste streams by significance of their environmental impact:........ ☐ Yes ☐ No

Established a system where all employees can generate, propose, and implement pollution prevention ideas: .... ☐ Yes ☐ No

Investigated opportunities to substitute hazardous chemicals with non-hazardous or less hazardous chemicals: .... ☐ Yes ☐ No

Implemented projects to substitute hazardous chemicals with non-hazardous or less hazardous chemicals: .... ☐ Yes ☐ No

9. Industrial Hygiene Practice

This information will be used to identify prevalent industrial hygiene practices.

Check Yes if performed during 1998. Otherwise check No.

Workplace air sampling is done regularly:........ ☐ Yes ☐ No

Workplace sampling is done when complaints are received:........ ☐ Yes ☐ No

Workers are provided with clothing (e.g., coveralls) that are laundered by your company on a regular basis:........ ☐ Yes ☐ No

Conducted regular medical surveillance:*........ ☐ Yes ☐ No

**For example, conducted blood testing for lead. Does not include employee drug testing.*

10. Pollution Control Cost Information

This information will be used to estimate the costs associated with environmental compliance and the potential costs savings associated with implementing pollution prevention.

Please provide the following cost information for 1998. For water, sewer and electricity, please provide the average unit price. For the remaining items, provide your total annual costs paid for 1998.

ITEM	1998 COST
Water........	$__________/1000 gal (or give units) __________
Sewer........	$__________/1000 gal (or give units) __________
Electricity........	$__________/kWh*
Wastewater treatment chemicals........	$__________
Misc. supplies (filter cloths, cartridge filters, etc.)........	$__________
Laboratory services........	$__________
Compliance/engineering services........	$__________
Sludge transportation/disposal/recycle........	$__________
Bulk chemical treatment........	$__________
Permits/Taxes/Licenses........	$__________
Other: ____________________........	$__________
Other: ____________________........	$__________

**For electricity provide the average unit cost (total dollars spent/total kWh consumed).*

11. Labor (1998)

Estimate the number of labor-hours spent during 1998 for each of the following tasks. Be certain not to "double count" hours that were spent on related tasks such as wastewater treatment operation and maintenance.

Item	1998 Labor Hours
Environmental management	________
Wastewater treatment operation	________
Monitoring	________
Inspection	________
Maintenance of pollution control systems	________
Analytical testing	________
Hazardous waste management	________
Waste reduction	________
Reporting/recordkeeping	________
Training	________
Local emergency planning	________
Other: ________	________
Other: ________	________

12. Process Specific Information

This information will be used to identify methods of pollution prevention that are used with specific types of processes.

Listed below are the processes you identified in your Phase I survey form. For each process, please provide a description of any pollution prevention (P2) and recovery methods or equipment that you have implemented/installed. Consider cleaning and post-plating processes that are associated with the listed process. Include P2 methods used for extending the life of process solutions, preventing drag-out, reducing water use, recovering chemicals, and substituting less toxic materials.

Process Name	Pollution Prevention Strategy
________	________
________	________
________	________

13. Describe below any special elements of your environmental compliance, pollution prevention or energy conservation programs not covered elsewhere in the survey form, especially those that you consider innovative. Include both management/employee elements (e.g., incentive programs, quality control programs) as well as equipment/facility elements (e.g., recycling equipment, energy conservation efforts).

Appendix 1B: Compilation of Survey Data

Table 1B-1 summarizes some of the raw data that was provided by companies responding to the Benchmarking Survey. To include all the survey data would have resulted in a confusing jumble of numbers. We selected a few items of particular interest, and arranged them in a way that will make them useful to the reader.

The first column is an identification (ID) number assigned arbitrarily to each company when we entered the information it supplied into the survey database. Because the numbers are arbitrary, the companies appear in no particular order.

The next three columns tell a "short story" about the company—its size (in terms of annual sales), customer mix, and process mix. From these numbers, the reader can form an impression of the nature of the company, of its business relationships, and of what goes on day-to-day on the shop floor.

The remaining seven columns summarize selected environmental performance measures, as reported by the company. The values can be used for selective benchmarking. Readers can look for companies similar to their own, and see how those companies' performance on each of the factors compares with their own.

We have rounded off the number values for two reasons. Firstly, the extra digits do not add any significant information when the numbers are used for benchmarking. Secondly, some of the numbers (such as annual sales) may have been published elsewhere by the companies (in annual reports, for example), and dollar figures that match in all the digits could conceivably be used to identify the company.

We are confident that the level of detail presented will not compromise confidentiality. Although those who have submitted data can probably pick out their line, the chance of anyone else being able to associate a particular line with a particular company is remote. The fact that we include 132 metal finishing facilities implies that perhaps 9,900 others (job shops and captives) do not appear here. We provide no geographic information, and we are not releasing the names of the companies who supplied data. Thus, there is no way that competitors, regulators, or concerned citizens could distinguish one company's data from that of a similar firm on the other side of the continent.

Table 1B-1. Benchmarking Survey Raw Data Summary

Key 1: Customers

Abbreviation	Customer
Aero	Aerospace/Aircraft
Bldg	Building/Construction
Boat	Boats/Ships
El, oth	Other Electronics
Fast	Fasteners
Furn	Furniture
Hdwr	Hardware/Tools
Hd, oth	Other Hardware
Hshld	Household Appliances
Hs, oth	Other Household Items
Jewel	Jewelry/Watches
Mach	Machinery/Industrial
Med	Medical
Mil	Military/Government
MotV	Motor Vehicles
Other	Other
Plmb	Plumbing Fixtures
PWB	Printed Wiring Boards
RR	Railroad
Sport	Sporting Goods/Toys
Wire	Wire Goods and Pipes

Key 2: Processes

Abbreviation	Process
Ag	Silver Plating
An, Cr	Anodizing (Chromic Acid)
Anod	Anodizing (Sulfuric Acid)
BlOx	Black Oxide
Brass	Brass Plating
Brnz	Bronze Plating
Cd	Cadmium Plating
ChMl	Chemical Milling
CrO_3	Chromating
Cu	Copper Plating
D Cr	Decorative Chromium Plating (Includes Cu, Ni Layers)
Derust	Derusting
EN	Electroless Nickel Plating
EPol	Electropolish
Fe	Iron Plating
H Cr	Hard Chromium Plating
Mass	Mass Finishing
Ni	Nickel Plating
Other	Small, Unspecified Process
Paint	Painting
Pass	Passivation
Phos	Phosphating
Powd	Powder Coating
Prec	Precious Metals Plating, Except Silver
Sldr	Hot Solder Dip (Molten)
Strip	Paint Stripping
Tin	Tin Plating
TinPb	Tin–Lead Plating
Vac	Vacuum Coating
Zn	Zinc Electroplating

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
3	0.4	Mach 100	H Cr 100	0.43	0.375	Local	1.4	0.0	No data	460
4	2.7	Boat 1 Hd, oth 9 Mach 28 Med 15 MotV 10 Plmb 28	D Cr 77.6 EN 4.6 EPol 17.8	1.2	0.75	413	0.0	0.0	0	1,050
5	1.0	Aero 15 Fast 5 Mach 75 Med 5	H Cr 100	0.08	0.00	?	0.0	0.0	0	420
6	0.2	Other 100	D Cr 100	0.50	0.50	Local	1.8	1.8	20	200
7	1.0	El, oth 5 Hdwr 5 Mach 5 Med 5 MotV 80	Zn 100	3.0	3.0	413	18.0	0.0	50	No data
8	3.9	Bldg 2 Fast 40 Mach 56 Mil 2	Zn 100	18.7	18.7	Both, Local	67.7	67.7	2	No data
9	2.0	Med 30 Other 70	EPol 100	0.26	0.20	Local	17.0	0.0	68	230
10	0.1	Hd, oth 100	Ag 53 Brass 23.5 Prec 23.5	0.20	0.15	413	2.5	2.5	80	No data
11	3.4	Aero 42 El, oth 42 Hdwr 10 Med 1 MotV 5	ChMl 100	1.03	1.03	433	87.1	0.0	40	No data
12	No data	Bldg 2 Fast 80 Furn 2 Hdwr 5 Hshld 3 Mach 3 MotV 3 Wire 2	BlOx 64 Pass 10 Phos 26	7.4	6.3	433, Local	1,080.0	0.0	65	2,490
13	1.5	Bldg 2 El, oth 1 Hdwr 14 Mach 1 Med 6 MotV 2 Plmb 3 Other 71	Ni 79 D Cr 21	0.0	0.0	?	53.4	0.0	94	280

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
14	2.2	Furn 25 Hdwr 10 Med 10 Wire 25 Other 30	D Cr 40 EPol 30 Zn 30	13.1	12.7	413	101.0	0.0	43	1,400
15	0.3	Fast 5 Hdwr 25 Mil 5 Sport 10 Other 55	Mass 100	0.26	0.23	433	0.0	0.0	No data	No data
16	0.9	MotV 80 Wire 20	D Cr 100	1.87	0.00	413	12.4	12.4	5	200
17	0.1	Mach 100	EN 10 H Cr 90	No data	0.001	413	0.0	0.0	0	40
18	2.7	MotV 85 Other 15	Paint 100	0.15	0.00	?	0.0	0.0	0	1,200
19	0.7	Bldg 30 Mach 70	H Cr 100	0.30	0.00	?	0.0	0.0	0	500
20	0.7	Aero 10 El, oth 60 Fast 10 Mil 10	Ag 60 EN 10 EPol 10 Phos 10 Zn 10	1.07	1.07	413	20.0	20.0	40	No data
21	3.2	El, oth 85 MotV 15	EN 26 Zn 74	3.8	2.7	Both	67.6	0.0	27	800
23	6.6	Bldg 40 El, oth 7 Fast 3 Furn 7 MotV 40 Wire 3	Zn 100	13.9	13.7	Both	312.0	0.0	50	2,580
24	1.7	Furn 3 Mach 12 MotV 9 Plmb 8 Sport 24 Other 44	D Cr 100	4.1	2.0	413	27.2	0.0	29	530
25	1.9	Mach 100	H Cr 100	0.04	0.00	Other	0.0	0.0	0	980
27	1.8	Bldg 5 Hdwr 15 MotV 20 Wire 30 Other 30	Zn 100	11.6	11.6	433	84.6	0.0	47	690
29	4.2	Fast 96 Other 4	Zn 100	7.8	7.2	433, Other	800.0	0.0	70	No data
30	2.0	Bldg 50 Other 50	H Cr 100	0.22	0.00		0.0	0.0	0	870

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
31	3.0	Fast 50 Hshld 10 Hs, oth 10 Mach 10 MotV 20	Zn 100	27.0	26.8	413	440.0	440.0	80	960
32	1.7	No data	Ag 9 EN 68 Prec 9 Other 14	6.5	6.5	413	0.0	0.0	0	110
33	No data	Aero 80 Other 20	Anod 100	0.0	0.0	?	5.5	0.6	20	No data
34	1.5	No data	Anod 32 BlOx 11 EN 19 Ni 25 Pass 5 Tin 5 Other 3	13.0	12.5	Local	0.0	0.0	No data	No data
36	7.3	Bldg 5 El, oth 10 Fast 5 Hs, oth 15 Mach 15 MotV 30 Wire 20	Phos 7 Zn 89 Other 4	35.0	35.0	Local	700.0	0.0	25	4,200
37	3.6	Bldg 5 Fast 50 Hdwr 10 Hs, oth 5 MotV 10 Sport 10 Wire 10	Zn 95 Other 5	16.5	16.5	413	187.1	187.1	5	1,140
38	0.8	No data	Ag 5 Ni 10 Tin 75 Zn 10	1.7	1.7	413	11.4	0.0	25	270
39	5.4	Aero 15 El, oth 50 Fast 5 Hdwr 5 Mach 10 Med 5 Mil 5 Wire 5	Cd 7 Cu 44 EN 10 Ni 13 Zn 23 Other 3	28.0	28.0	413	280.1	280.1	25	900
40	0.6	Other 100	Anod 100	0.52	0.25	Local	225.6	225.6	98	330

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
41	5.0	Bldg 7 Furn 3 Hdwr 25 Mach 5 MotV 20 Plmb 40	Brass 3 D Cr 90 Other 7	3.8	3.5	413, Local	50.0	50.0	20	500
42	3.6	Aero 5 Boat 3 Bldg 8 El, oth 5 Fast 1 Hdwr 1 Hs, oth 6 Mach 28 Med 6 Mil 6 MotV 15 RR 1 Other 15	Anod 92 Paint 6 Other 2	8.2	7.5	Local	14.3	0.0	0	3,200
43	9.5	Aero 10 El, oth 50 Fast 10 Hdwr 5 Mach 15 Med 5 Mil 2 Wire 3	Cd 6 D Cr 4 Ni 14 Pass 3 Tin 10 Zn 59 Other 4	35.9	32.8	Local	0.0	0.0	0	4,700
44	10.0	Furn 10 Hdwr 5 Hs, oth 40 Mach 10 MotV 30 Wire 5	Brass 14 D Cr 42 EN 15 Ni 17 Paint 5 Zn 5 Other 2	30.0	30.0	Both	300.0	0.0	20	3,230
46	2.5	Aero 18 El, oth 12 Fast 5 Hs, oth 2 Jewel 2 Mach 8 Med 9 Mil 10 MotV 17 Plmb 3 RR 1 Sport 13	Ag 4 Anod 21 BlOx 9 Brass 2 Cd 16 D Cr 7 EN 8 H Cr 3 Pass 2 Zn 19 Other 9	14.0	14.0	Local	9.8	0.0	20	1,080

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
47	4.4	Bldg 1 Fast 5 Furn 3 Hdwr 10 Hshld 7 Hs, oth 10 Mach 52 Mil 2 MotV 2 Plmb 4 Sport 2 Wire 2	BlOx 5 D Cr 12 EN 4 Ni 5 Phos 5 Zn 65 Other 4	3.2	8.9	413	139.3	0.0	36	3,080
48	1.3	Bldg 42 El, oth 13 Fast 13 Furn 2 Hdwr 2 Hshld 1 Hs, oth 2 Mach 18 MotV 5 Plmb 1 Wire 1	H Cr 20 Ni 5 Paint 8 Phos 10 Zn 53 Other 4	2.2	2.0	413	4.5	4.5	25	200
49	2.0	Aero 2 Mach 93 Mil 5	Anod 6 EN 65 H Cr 10 Prec 8 Other 11	1.2	0.005	?	17.8	0.0	No data	290
50	3.7	Hdwr 20 Mach 10 MotV 25 Sport 25 Wire 20	Paint 50 Zn 46 Other 4	14.0	14.0	413	146.0	146.0	5	1,980
51	1.1	Fast 4 Mach 90 MotV 1 Wire 5	EN 5 Zn 89 Other 6	2.4	2.38	Local	41.2	41.2	20	No data
52	3.4	Aero 5 Fast 5 Furn 15 Hdwr 20 Hshld 20 Mach 15 MotV 5 Wire 15	BlOx 8 Cu 7 D Cr 33 Phos 8 Zn 36 Other 8	19.6	19.6	413	145.7	0.0	53	890

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
53	3.4	Aero 80 El, oth 20	Anod 17 An, Cr 16 Cd 9 EN 15 Ni 5 Paint 7 Pass 3 Prec 9 Zn 7 Other 12	4.8	4.0	Local	19.2	19.2	42	940
54	1.5	Bldg 35 Boat 5 Hdwr 5 Hshld 10 Hs, oth 10 Mil 10 MotV 10 Other 15	Brass 25 CrO3 5 D Cr 40 H Cr 5 Ni 10 Prec 15	1.5	1.0	413	5.0	0.0	10	No data
55	0.7	Aero 1 Bldg 8 Fast 5 Mach 25 Mil 1 MotV 45 Other 15	BlOx 8 Cd 2 D Cr 8 EN 40 H Cr 35 Pass 4 Other 3	1.3	0.98	413	0.2	0.2	10	320
56	0.8	Aero 65 El, oth 2 Mach 20 Mil 5 MotV 8	Cd 10 D Cr 10 Ni 65 Pass 5 Prec 10	3.3	2.2	Both	5.7	0.0	40	250
57	8.2	Bldg 3 El, oth 72 Fast 1 Mach 20 Mil 2 MotV 2	Paint 7 Powd 17 Zn 71 Other 5	23.4	18.1	413	111.5	0.0	32	4,440
58	8.3	Aero 1 Boat 2 El, oth 3 Fast 1 Hdwr 3 Hshld 2 Mach 70 Med 2 Mil 3 MotV 10 RR 1 Sport 1 Other 1	Anod 45 BlOx 9 CrO3 10 EN 27 Zn 5 Other 4	12.0	11.6	Local	0.0	0.0	0	1,530

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
59	0.6	Bldg 5 Fast 5 Hdwr 10 Mach 10 MotV 25 Wire 20 Other 25	BlOx 10 Ni 35 Pass 9 Zn 43 Other 3	0.95	0.95	413	52.5	52.5	79	190
60	3.6	Bldg 5 El, oth 54 Fast 2 Furn 2 Hs, oth 2 Mach 2 MotV 27 Wire 6	Zn 97 Other 3	41.5	41.5	Local	320.3	320.3	70	3,150
61	0.9	Aero 16 Bldg 2 Boat 1 Fast 1 Hdwr 2 Mach 60 Med 10 MotV 5 Sport 3	Anod 80 CrO3 18 Other 2	1.36	1.29	?	0.0	0.0	0	180
62	2.9	Aero 30 El, oth 30 Mach 20 Med 10 Plmb 10	Anod 28 CrO3 11 Paint 36 Phos 5 Powd 13 Other 7	8.5	7.5	433	1.7	0.0	3	930
63	No data	El, oth 20 Fast 10 Mach 5 Med 2 MotV 55 Wire 5 Other 3	D Cr 10 Ni 5 Tin 25 Zn 60	1.5	1.48	Local	198.0	198.0	95	No data
64	3.2	Fast 2 Jewel 69 Other 29	Ag 9 Ni 23 Prec 61 Other 7	26.3	24.2	Local	0.0	0.0	0	430
65	6.4	Fast 35 Hdwr 15 Hshld 30 Mach 1 Mil 2 MotV 15 Sport 2	BlOx 5 Phos 59 Zn 34 Other 2	34.3	34.3	413	434.0	0.0	50	1,500

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
66	5.4	Aero 83 Fast 15 Mach 2	Cd 15 Cu 11 EN 5 H Cr 57 Pass 10 Other 2	3.2	2.9	Both	12.0	0.0	35	No data
67	3.8	Boat 5 El, oth 25 Fast 5 Hdwr 10 Hshld 5 Hs, oth 20 Mach 5 Med 20 Plmb 5	Cu 10 D Cr 10 EPol 10 Ni 66 Other 4	12.0	11.0	Both	256.7	0.0	75	1,250
68	5.0	Hdwr 85 Mach 15	H Cr 99 Other 1	7.4	0.6	433	88.1	0.0	37	2,630
69	23.0	Aero 10 El, oth 50 Med 2 Mil 8 MotV 22 PWB 8	Ag 20 Cu 2 Ni 3 Prec 50 Tin 15 TinPb 10	29.8	29.8	413	102.2	0.0	40	3,010
70	0.7	Other 100	Anod 60 CrO3 35 Pass 5	0.1	0.0	433	24.0	0.0	85	No data
71	3.6	Bldg 10 El, oth 5 Hdwr 30 Hs, oth 30 Mach 10 Plmb 5 Wire 10	D Cr 54 Tin 8 Zn 36 Other 2	28.0	22.7	413	72.0	0.0	45	1,210
72	3.3	Aero 15 Bldg 5 Hshld 5 Mach 25 Mil 20 MotV 25 Wire 5	Anod 23 Tin 4 Zn 59 Other 14	13.3	13.0	413	51.5	51.5	20	1,280
73	0.8	Aero 5 Hdwr 20 Mil 15 MotV 20 Sport 20 Wire 20	Cd 8 Phos 14 Zn 69 Other 9	2.8	2.2	Local	0.0	0.0	0	No data

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
74	2.6	Furn 20 Hdwr 15 Mach 15 Wire 50	D Cr 38 Powd 24 Zn 38	14.8	14.4	413	160.2	160.2	74	1,630
75	2.3	Boat 4 Fast 6 Mach 40 Med 2 Other 48	D Cr 60 H Cr 39 Other 1	No data	3.6	413	24.0	0.0	68	940
76	27.1	El, oth 4 Mil 1 MotV 95	Ni 95 Prec 5	20.9	71.7	Local	1,295.2	0.0	40	11,040
78	2.0	Hdwr 20 Mach 50 Sport 30	BlOx 5 Cu 5 D Cr 20 H Cr 70	9.0	7.2	Both	170.0	30.5	40	1,110
79	19.4	MotV 100	EPol 38 Phos 10 Zn 52	146	146	413	4,300.0	0.0	70	8,000
80	0.5	Other 100	EPol 100	0.001	0.000	Local	0.0	0.0	99	No data
81	4.8	Bldg 5 Fast 88 Furn 1 Hs, oth 1 Plmb 1 Other 4	CrO3 9 Pass 13 Phos 35 Zn 43	11.0	10.70	Both	2,609.3	0.0	60	2,670
82	0.7	Mach 10 MotV 30 Plmb 10 Other 50	D Cr 90 H Cr 10	1.00	0.8	413	19.2	19.2	90	290
83	2.6	Aero 25 Boat 10 Mach 60 Wire 5	EN 5 H Cr 95	0.18	0.16	Other	49.0	49.0	60	No data
86	0.1	Aero 1 Boat 3 Other 96	Ni 100	0.1	0.09	?	0.3	0.3	60	90
87	7.9	Fast 1 MotV 99	Anod 27 Zn 73	27.1	27.1	Both	1,220.0	1,220.0	45	5,160
88	1.0	El, oth 90 Sport 10	Anod 40 EN 40 Pass 20	0.75	0.70	Local	1.0	0.0	20	100
89	0.8	El, oth 10 Fast 5 Hdwr 30 Mach 50 Med 5	H Cr 95 Pass 5	0.0	0.0	413	0.0	0.0	0	160

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
90	1.1	Mach 6 Mil 47 Wire 47	Anod 11.1 An, Cr 11.1 BlOx 11.1 Cd 11.2 CrO3 11.1 EPol 11.1 Paint 11.1 Pass 11.1 Phos 11.1	0.42	0.417	433	48.0	48.0	50	290
91	No data	Furn 32 Hdwr 14 Hshld 9 Med 5 MotV 38 Wire 2	D Cr 94 Zn 5 Other 1	No data	27.7	Local	74.5	0.0	7	2,390
92	3.9	No data	Anod 90 CrO3 10	4.5	4.5	Local	0.0	81.8	60	800
93	3.9	Bldg 10 Fast 15 Hdwr 5 Hshld 5 Hs, oth 5 Mach 5 MotV 30 Sport 10 Wire 5 Other 10	Anod 14 Cu 9 Phos 5 Zn 72	16.2	16.2	413, Local	472.6	472.6	70	3,000
95	3.3	Mach 100	EN 14 H Cr 86	4.04	0.22	Both	77.5	0.0	60	2,480
96	6.0	Aero 40 El, oth 20 Mil 20 MotV 20	Ag 10 Ni 10 Prec 70 TinPb 4 Other 6	20.0	20.0	413	24.1	0.0	60	1,320
97	1.3	Mach 85 Mil 10 MotV 5	H Cr 100	0.05	0.00	Other	1.2	0.0	50	370
98	6.8	Fast 60 Hshld 5 Mach 5 MotV 30	Zn 100	38.6	38.6	413	87.2	0.0	No data	2,330
99	1.2	Aero 10 El, oth 60 Fast 5 Mach 5 Med 15 Sport 5	Anod 70 Cu 30	2.09	1.98	413	6.0	0.0	5	290

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
100	27.0	No data	Anod 65 CrO3 5 EN 30	141	139	Local	54.0	0.0	20	11,000
101	7.1	Bldg 2 Fast 3 Mach 2 MotV 93	Cu 21 Paint 9 Zn 70	26.0	25.6	Local	716.0	0.0	68	5,240
104	8.7	El, oth 5 Fast 5 Mach 60 Mil 5 MotV 15 Wire 10	Anod 19 BlOx 4 EN 35 Zn 40 Other 2	24.5	24.5	Local	544.4	544.4	15	2,860
105	1.4	Aero 5 Fast 20 Mach 4 Med 1 Mil 25 MotV 36 Plmb 3 Wire 6	Cd 8.6 Paint 7.2 Pass 1.4 Phos 27.8 Tin 3.6 Zn 50.7 Other 0.7	12.0	12.0	413	1.0	0.0	No data	380
106	1.2	Bldg 10 Furn 50 Hdwr 20 Mach 20	Brass 30 Cu 35 Ni 10 Zn 25	5.9	5.9	413	37.8	37.8	60	240
107	3.5	Aero 15 Bldg 2 El, oth 40 Fast 4 Furn 3 Hdwr 3 Hs, oth 3 Jewel 2 Mach 15 Med 2 Mil 2 MotV 3 Sport 2 Wire 4	Anod 15 Cd 5 CrO3 10 EN 5 Ni 5 Prec 5 Tin 5 Zn 50	3.2	2.6	Both, Local	142.6	142.6	55	1,570
108	4.5	El, oth 100	Tin 5 TinPb 95	2.7	2.5	433	18.9	18.9	43	1,070
109	12.5	Bldg 5 Fast 84 MotV 10 Other 1	Ni 6 Phos 4 Zn 90	4.9	97.8	413	1,300.0	300.0	75	5,660
110	3.4	Hdwr 10 Hs, oth 30 Med 10 MotV 50	Phos 5 Zn 95	21.7	21.7	?	219.4	199.0	75	1,250

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
111	0.8	Aero 5 Fast 5 Hshld 25 Hs, oth 15 Mach 25 MotV 20 Wire 5	Derust 30 Powd 10 Strip 60	0.1	0.0	433	2.0	0.0	No data	90
112	6.5	MotV 100	Zn 100	10.2	9.0	413	235.6	71.1	70	No data
113	2.5	Aero 7 El, oth 32 Fast 3 Furn 2 Hshld 2 Mach 5 Other 49	Ag 4.4 CrO3 18.6 EN 3.7 Ni 5.8 Sldr 26.9 Tin 5.4 Zn 35.2	2.7	2.4	413, Local	20.0	0.0	40	430
114	3.0	Bldg 20 Fast 40 MotV 20 Wire 20	Phos 7 Zn 88 Other 5	12.9	11.6	413	260.0	0.0	20	1,140
115	3.9	Fast 10 Mach 20 MotV 50 Wire 10 Other 10	BlOx 10 CrO3 30 Paint 15 Zn 45	No data	18.7	433	536.5	0.0	78	No data
116	0.6	Aero 5 El, oth 10 Mach 66 Mil 19	EN 100	0.47	0.40	Other	3.6	0.0	60	260
117	0.6	El, oth 15 Fast 5 Hdwr 45 Mach 30 Wire 5	CrO3 5 D Cr 45 Ni 14 Paint 15 Pass 1 Zn 20	0.50	0.45	433	4.0	1.0	2	90
118	7.2	Aero 79 Fast 17 Mach 4	Anod 16 Cd 4 Paint 24 Pass 5 Vac 41 Other 10	4.7	3.5	Both	4.0	4.0	No data	1,750
119	0.8	Bldg 5 Boat 3 El, oth 2 MotV 5 Plmb 5 Other 80	Brass 10 D Cr 50 Ni 20 Zn 10	0.25	0.20	Local	2.0	2.0	10	No data
120	6.9	Fast 99 Hdwr 1	Phos 10 Zn 90	18.9	18.8	433	720.0	30.0	80	4,320

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
121	10.0	Aero 60 Furn 3 Hdwr 5 MotV 2 Plmb 10 Other 20	Ag 6 Brass 6 Brnz 6 Cu 6 D Cr 25 Ni 6 Prec 40 Other 5	10.7	9.7	Both, Local	121.0	0.0	70	1,070
122	4.0	Bldg 9 El, oth 25 Furn 4 Hdwr 4 Hshld 19 Mach 4 Med 4 Mil 4 MotV 19 Sport 4 Wire 4	Anod 40 An, Cr 15 Paint 5 Zn 40	23.3	21.1	Local	62.8	62.8	50	1,710
123	2.2	Bldg 4 Fast 3 Hdwr 3 Mach 22 MotV 1 Other 67	H Cr 56.8 Zn 43.2	0.5	0.06	?	0.0	0.0	0	1,010
124	4.9	Fast 5 Hdwr 5 Mach 15 MotV 50 Other 25	EN 80 H Cr 20	11.4	6.5	413	54.0	54.0	68	100
125	No data	Other 100	No data	No data	0.118	433	2.6	0.0	70	1,200
126	3.0	El, oth 30 Fast 10 Hshld 10 MotV 50	Ag 10 Ni 14 Prec 5 Tin 50 Zn 20 Other 1	6.0	5.4	Local	84.9	0.0	60	520
127	1.8	Aero 10 Bldg 10 Fast 30 Furn 10 Hdwr 3 MotV 10 Plmb 5 RR 5 Wire 5 Other 12	BlOx 10.1 Brass 10.2 Ni 10 Zn 69.7	1.9	1.7	413, Local	123.4	123.4	65	440
128	No data	Other 100	D Cr 100	16.4	16.4	413	0.0	0.0	No data	5,500
129	3.4	Other 100	H Cr 100	0.0	0.0	Both	11.0	11.0	90	1,770

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
132	12.1	Bldg 20 El, oth 5 Fast 2 Furn 2 Hdwr 5 Mil 1 MotV 61 Other 4	Anod 10 Cd 8.3 D Cr 38.4 H Cr 16.7 Prec 13.3 Zn 13.3	56.0	48.0	413	440.5	0.0	35	7,050
133	9.1	Bldg 5 Fast 10 Hdwr 5 MotV 80	Zn 95 Other 5	55.3	55.0	433	937.0	7.0	60	6,000
134	4.0	Aero 3 Bldg 17 El, oth 4 Fast 8 Furn 3 Hdwr 3 Jewel 17 Med 3 MotV 17 Plmb 17 Sport 8	Brass 11 Cu 11 D Cr 11 Mass 6 Ni 61	2.8	2.0	Local	30.0	30.0	50	970
135	8.2	Aero 70 Boat 3 El, oth 1 Hdwr 2 Mach 5 Med 5 Mil 14	Anod 23.1 Cd 15 H Cr 14 Other 47.9	8.3	8.3	413	48.7	0.0	45	5,430
136	3.7	Aero 20 El, oth 5 Mach 20 Med 5 Mil 10 MotV 40	EN 60 Paint 5 Pass 8 Phos 25 Other 2	6.6	4.7	433, Local	27.8	27.8	25	1,500
137	10.0	MotV 100	H Cr 100	1.5	0.9	413, Local	17.7	0.0	72	2,600
138	10.6		Anod 15 CrO3 15 D Cr 30 Pass 5 Zn 33 Other 2	67.6	60.8	?	226.1	226.1	60	5,510

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
140	6.8	Aero 3 Fast 5 Hdwr 13 Hs, oth 5 Mach 3 Mil 5 MotV 5 Sport 6 Other 55	Ag 3.0 Anod 3.0 Cd 19.5 CrO3 7.3 D Cr 3.0 EN 5.4 Ni 16.3 Tin 12.6 Zn 13.6 Other 16.3	40.4	24.5	413, Local	396.0	0.0	61	2,870
141	0.8	Aero 1 Hdwr 30 Mach 50 Med 5 MotV 1 Plmb 10 Other 3	Anod 10 D Cr 20 EN 15 H Cr 10 Paint 5 Phos 15 Zn 15 Other 10	5.3	4.8	413	4.0	4.0	35	740
142	3.9	Aero 2 Bldg 3 El, oth 30 Fast 1 Furn 1 Hdwr 9 Hshld 1 Mach 16 Mil 1 MotV 35 Wire 1	Zn 100	18.0	14.0	413	450.0	450.0	85	960
144	9.0	Aero 3 Bldg 1 Hdwr 1 Mil 1 MotV 93 Sport 1	Brnz 40 EN 50 Zn 10	25.0	20.0	413	50.4	50.4	5	1,400
145	2.0	Fast 6 Hdwr 5 Hshld 10 Hs, oth 6 Mach 6 MotV 39 Wire 28	Zn 100	8.2	8.2	413	86.7	0.0	35	1,320

Table 1B-1. Benchmarking Survey Raw Data Summary (continued)

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)	Water Purchased, millions gal/yr	Wastewater Discharged, millions gal/yr	Regulations Applied	Sludge Generated, thousands lb/yr	Hazardous Sludge Shipped Offsite, thousands lb/yr	Water content, %	Electricity Used, thousands kWh/yr
146	3.0	Aero 50 El, oth 10 Fast 5 Mach 5 Med 2 Mil 25 Sport 1 Wire 2	Ag 6.0 Cd 23.0 EN 31.0 EPol 13.0 Ni 6.0 Paint 0.8 Pass 6.0 Tin 2.0 Other 12.2		1.0	413	65.2	26.2	20	450
147	10.5	Aero 10 El, oth 70 Jewel 4 Med 1 Mil 15	Ag 20 EN 5 Ni 5 Prec 60 Tin 5 Other 5	7.2	5.7	Local	238.7	0.0	68	2,120
148	1.4	Hdwr 100	EN 20 Fe 40 H Cr 20 Ni 20	1.0	0.4	433	8.9	0.0	50	500
149	2.0	No data	Ag 10 Anod 30 BlOx 10 Cd 5 D Cr 10 EN 10 Ni 15 Paint 10	0.9	0.7	Local	6.3	0.0	10	490

Appendix 1C: Additional Details on Survey Methods and Analytical Approach

This appendix contains technical background relevant to the results developed in Chapter 1. It is not intended to be a short course in statistics (for that, the reader is referred to standard textbooks on the subject). However, it should provide enough information so that informed readers can evaluate our methods and conclusions. Also included are some observations, valuable in their own right, concerning various issues involved in conducting this type of analysis on any data set.

Edith Wiarda provided the material for this appendix.

1C.1 Analytical Approach

Our approach was designed to address several important issues and concerns.

1C.1.1 What Exactly Do We Mean by "Environmental Performance?"

Here, we were fortunate to be able to build upon the work of the Strategic Goals Program, which has developed a set of measures that allow a company to track *its own* improvement over time. The SGP metrics represent the consensus view of industry and government on the most important elements of environmental performance. They are:

- Gallons of water discharged per year
- Pounds of wastewater treatment sludge generated per year, adjusted for water content, i.e., total pounds of sludge (1 - percent water content/100). (Hereafter, referred to simply as "sludge.")
- Pounds of hazardous wastewater treatment sludge that is shipped offsite for land disposal per year, adjusted for water content. (Hereafter, abbreviated as "hazardous sludge land-disposed.")
- Total pounds of Toxics Release Inventory (TRI) list organic chemicals released to air and water per year. (Hereafter, "organic chemical emissions.")
- Electricity consumption per year, in kWh.
- Total energy consumption (all fuels) per year, in Btu.

These data formed the core of the Phase 1 Benchmarking Survey.

1C.1.2 How Do We Normalize These Performance Figures To Adjust for Differences in Plant Size?

Certainly, large facilities should not be penalized for generating more total waste or using more total energy. The usual approach is to select some measure of plant size—typically sales, value-added (sales less purchased inputs), or employment—to serve as a normalizing factor or denominator. Each company's performance data is divided by the normalizing factor, so that its figures can be compared on a "per dollar of sales" or "per employee" basis.

However, there is no obvious best measure of "size" or "output" for the metal finishing industry. Two different plating plants might have identical sales or employment figures, and yet, due to differences in market and pricing conditions or to different part geometries, be applying very different quantities of metal.

Our approach was to gather data on several alternative normalizing factors and then to evaluate the results. These factors are:

- Sales (dollars per year)
- Value added (sales minus purchased inputs and purchased subcontracting, in dollars per year)

- Metal finishing shop labor hours per year
- Surface square feet (ssf) of material plated per year
- Rectifier amp-hours used per year.

We would expect that the better the normalizing factor, the less variation or spread in the resulting performance metrics. Thus, we will compute some standardized measures of variation (including the standard deviation divided by the mean, and the interquartile range divided by the mean) to see if any of these choices outperform the others.

1C.1.3 How Do We Account for Process Differences When Comparing Environmental Performance Across Companies?

Metal finishing is characterized by huge variety in the number of distinct processes carried out. Some processes are inherently “dirtier” or more energy intensive than others. The issue is further complicated by the fact that most metal finishing plants do more than one process. We cannot simply divide the facilities into distinct groups of “zinc platers” versus “nickel platers” versus “anodizers,” for example, for purposes of comparing them only against their peers. Nor can we ask survey participants to report separately on the energy consumption, sludge generation, and water discharges *by process*. Most firms keep these data only on a facility-wide basis.

A statistical technique called regression analysis provides a useful approach. For each plant, we gathered data on its “process mix”—that is, what percentage of the work the plant attributes to each of its major processes. (This might be measured as percent of sales attributable to each, or as percent of labor hours, for example.) Then, for common processes used by a sizeable number of survey participants, we used regression analysis to separate out the influence of process type on a company’s performance scores.

1C.1.4 What Are the Implications of Basing the Analysis on a Non-random, Non-representative Sample of the Industry?

We knew in advance that Benchmarking Survey participants would not constitute a random cross section of the metal finishing industry. Enticing busy managers at small firms to fill out a survey form is never easy—substantial self-selection bias is the inevitable result. Also, we expected SGP participants to contribute disproportionately to the results (as indeed they did).

For this survey project, there was simply no way to enforce a random sampling of participants. Instead, we planned to evaluate as best we could the ways in which participants differ from the industry as a whole. An obvious place to start is with SGP participants. Our analysis plan called for explicitly including SGP participation as a factor in our regression analysis. That allows us to determine whether being an SGP participant, in and of itself, is associated with better performance scores. If yes, then we know that our sample is biased toward good performers. Further, the analysis would then provide an estimate of just how much better the firms that participate in the SGP tend to be, allowing us to gauge how our results should be adjusted to be more reflective of the industry at large.

1C.2 Environmental Performance Metrics and Normalizing Factors

1C.2.1 Survey Response: Numerators

As shown in Table 1C-1, survey participants were willing and able to provide data on water discharged, sludge generated, hazardous sludge land-disposed, and electricity consumption. Of these, most notable is the fact that almost 60% of the plants report zero hazardous sludge land-disposed. (Respondents were instructed to enter “0” if their wastewater treatment sludge was delisted, or if they ship it offsite for metals recovery rather than disposal.)

Table 1C-1. Survey Response Rates, Performance Metrics Numerators

Performance Metric	Number (Percent) of Plants Providing Data	Of Those Providing Data, Number (Percent) Reporting Value of 0
Water Discharged, gal	132 (100)	14 (10.6)
Sludge Generated, lb	121 (91.7)	16 (13.2)
Hazardous Sludge Land-Disposed, lb	122 (92.4)	71 (58.2)
Organic Chemical Emissions, lb	128 (97.0)	84 (65.6)
Electricity Consumption, kWh	112 (84.8)	0 (0.0)
Total Energy Consumption, Btu	111 (84.1)	0 (0.0)*

* 11 plants (9.9%) report 0 for all fuels other than electricity.

We have strong confidence in the data on water discharged and kilowatt–hour consumption. We have somewhat less confidence in the water content figures that underlie the sludge generated and sludge land-disposed figures. For example, 15 firms (12.4 % of those who provided total sludge data) did not give water content data, but did indicate the type of dewatering technology used. For these 15, we substituted an approximate water content percent.

At first glance, overall response also looks good for organic emissions and total energy use. However, there are reasons to be suspicious of both. The percentage of firms reporting zero organics emissions is unreasonably high. We suspect a large fraction should really be "unknown," not zero. Regarding total energy, 10% of the firms indicated they use no energy other than electricity. This response also strikes us as implausible, and may indicate reporting errors.

Note that the measures of chemical emissions and total energy use yielded the least satisfactory statistical results, perhaps confirming our concerns about data quality.

1C.2.2 Survey Response: Denominators

Of the possible normalizing factors, sales had the best survey completion rate, as shown in Table C1-2. In contrast, neither amp–hours nor surface square feet (ssf) proved to be feasible normalizing factors, as few firms provided data on either.

Table 1C-2. Percent of Respondents Providing Data By Normalizing Factor

Normalizing Factor	Number (Percent) of Participants Providing Data
Sales	126 (95.4)
Value Added*	108 (81.8)
Labor Hours	97 (73.5)
Amp–Hours	37 (28.0)
Surface Square Feet (ssf)	26 (19.7)

* Sales less purchased materials and subcontracting.

1C.2.3 Comparing Alternative Normalizing Factors

Table 1C-3 provides the results from an analysis of three normalizing factors: sales, value added, and labor hours. For each of these three factors, it presents three different measures of spread or variation, for each of the six "numerators." The three measures of variation are:

1. *Standard deviation/mean:* based on all data points, even extreme values or outliers
2. *(90^{th} percentile - 10^{th} percentile) / mean:* excludes the bottom 10% and the top 10%, so does not reflect extreme values or outliers
3. *(75^{th} percentile – 25^{th} percentile) / mean* (sometimes called the standardized interquartile range): based solely on the middle 50% of observations, so reflects the variation only in that middle group.

An asterisk indicates which of the three normalizing factors in that row yielded the least variation in the result. Sales is clearly the best normalizing factor when variation is measured as the standard

Table 1C-3. Comparison of Variation or Spread in Performance Metrics: Sales vs. Value Added vs. Labor Hours

Measure of Variation or Spread	Performance Metric Numerator	Normalizing Factor or Denominator		
		Sales, $	Value Added, $	Labor Hours
Standard deviation / mean ($s / \bar{X}$)	Water discharged	0.950 *	0.951	0.965
	Sludge generated	1.58 *	1.72	1.80
	Hazardous sludge land-disposed	2.06 *	2.07	2.38
	Organic chemical emissions	2.52	2.44 *	2.75
	Electricity use	0.571 *	0.645	0.685
	Total energy use	1.15	1.06	1.01 *
10th to 90th percentile range / mean [$(P_{90} – P_{10}) / \bar{X}$]	Water discharged	2.07	2.04 *	2.16
	Sludge generated	2.14 *	2.14 *	2.33
	Hazardous sludge land-disposed	2.48	2.38	2.10 *
	Organic chemical emissions	3.14 *	3.18	3.68
	Electricity use	1.36 *	1.46	1.73
	Total energy use	1.45 *	1.56	1.56
25th to 75th percentile range / mean [$(P_{75} – P_{25}) / \bar{X}$]	Water discharged	1.20	1.30	0.968 *
	Sludge generated	1.08	1.09	0.947 *
	Hazardous sludge land-disposed	1.01	1.04	0.958 *
	Organic chemical emissions	1.05	1.01 *	1.14
	Electricity use	0.711 *	0.790	0.905
	Total energy use	0.853	0.887	.784 *

* Indicates the normalizing factor yielding the least variation or spread in that row.

deviation / mean. It yields the lowest variation for four of the six numerators. Sales also looks best when variation is measured by the second method, again giving the lowest variation for four of the six numerators. In contrast, labor hours looks the best when considering only the middle half of the observations.

These observations suggest that metrics based on value added or labor hours have more outliers or extreme values than do metrics based on sales. A likely cause of this would be that the sales figures themselves are more accurate (that is, introduce less error) than either the value-added or the labor hours data. The fact that labor hours does better for the middle core of observations suggests that labor hours might be an excellent normalizing factor if we could clean up inaccuracies.

Based on these results, we use sales as the preferred normalizing factor. The statistical results reported below have been replicated using both labor hours and value added as normalizing factors as well. However, in this document we report only the sales results.

Note also that no matter how it is measured, electricity use shows the least underlying variation in performance. Organic chemical emissions show the most.

1C.2.4 Distribution of Environmental Performance

Table 1C-4 describes the range of performance scores, by performance metric. These distributions include only those survey participants who reported non-zero values.

Table 1C-4. Distribution of Performance Among Survey Participants, Six Metrics

Performance Metric	N with > 0 Values	Mean	10th Percentile	25th Percentile	Median	75th Percentile	90th Percentile
Water discharged, gal/$ sales	108	2.873	0.282	0.945	2.18	4.379	6.222
Sludge generated, lb/$ sales	97	0.0191	0.00161	0.00347	0.0111	0.024	0.0412
Hazardous sludge land-disposed, lb/$ sales	49	0.0146	0.00128	0.00347	0.00844	0.0182	0.0375
Organic chemical emissions, lb/$ sales	41	0.00144	0.0000116	0.00013	0.000759	0.00164	0.00453
Electricity use, kWh/$ sales	104	0.402	0.153	0.239	0.373	0.525	0.701
Total energy use, Btu/$ sales	103	4753	1108	1801	3820	5855	8021

1C.3 A Simple Regression Model of Environmental Performance Versus Process Type: How To Interpret the Results

The regression results reported in Chapter 1 are based on the following regression model:

$$y_i = a_1 P_{1i} + a_2 P_{2i} + \ldots + a_n P_{ni} + e_i$$

where:

y_i = the value of a performance metric (for example, kWh/$ sales) for plant i

$P_{1i}, P_{2i}, \ldots, P_{ni}$ = the fraction of plant i's sales attributable to process type1, process type 2, and so on through process type n. Note that:

$$\sum_{j=1}^{n} P_{ji} = 1$$

that is, the fraction of sales accounted for by all process types must sum to 1.

$a_1, a_2, \ldots, a_n$ = coefficients associated with process 1, process 2, …, process n, respectively

e_i = a random component of plant i's value of y_i, that is, the part that is not explained by its process mix. We assume this random component is normally distributed with mean zero.

We have data on y_i and on the set of P_{ji}'s for each survey participant. We then use regression analysis to compute estimates for the process coefficients, denoted as $\hat{a}_1, \hat{a}_2, \ldots, \hat{a}_n$.

That is, regression analysis allows us to compute an "expected" or "average" value of y_i, denoted as $\hat{y}_i$, given any set of values for the P_{ji}'s, as follows:

$$\hat{y}_i = \hat{a}_1 P_{1i} + \hat{a}_2 P_{2i} + \ldots + \hat{a}_n P_{ni}\,.$$

To understand how to interpret the meaning of the coefficients, consider the case of a hypothetical company that does only process type 1, i.e., it has values $P_1 = 1$, $P_2 = 0$, $P_3 = 0$, …, $P_n = 0$. For a company doing only process 1, the expected or "average" value of y is:

$$\hat{y} = \hat{a}_1 1 + \hat{a}_2 0 + \ldots + \hat{a}_n 0 = \hat{a}_1\,.$$

Thus, the interpretation of the coefficients is straightforward. For any process type, the associated value of $\hat{a}_i$ is just the expected value (or "average") for firms that do only process *i*.

Similarly, consider a plant that is 50% process 1 and 50% process 2. For this plant:

$$\hat{y} = \hat{a}_1(.5) + \hat{a}_2(.5) + \ldots + \hat{a}_n 0 = .5\hat{a}_1 + .5\hat{a}_2\,.$$

In other words, we can compute the expected or average value of y for any plant by simply taking a weighted average of the $\hat{a}_i$'s. The weights are nothing but the share of sales attributable to each process.

A statistical note: We use a slight variation of this model, omitting one of the process types and allowing the estimation of an intercept term, in order to perform some simple statistical tests.

In this version, the significance of the F statistic tests whether or not controlling for process mix as a whole (that is, including all the P_{ji}'s in the model) is statistically different from not controlling for process mix. Also, the significance of the t-statistic on each coefficient provides a pairwise test of whether that process is statistically different from the omitted process.

1C.4 "Adjusted" Performance Scores: Making Valid Comparisons Across Plants

By using regression analysis, we have seen that process mix is a powerful explanatory factor underlying differences in reported environmental performance. We have also seen that differences in rack versus barrel processing are sometimes important, and that regulatory regime and "repetitiveness" seem less so.

In Chapter 1, Section 1.3.4, our goal was to use the regression technique to arrive at an "adjustment formula" for each performance metric. By "adjustment formula," we mean a formula for taking a plant's own value, and then stripping out the influence that can be attributed to its process mix (and potentially other important characteristics), on average. What is left can be thought of as the facility's "process-free" score. A complete set of these "process-free" scores can be computed for all plants. The results allow valid comparisons across plants—comparisons that are truly "apples to apples."

Here is the technique. Let us assume that we have arrived at a "best" or "preferred" regression model for a particular performance metric. This model will certainly include process mix, but may include other factors as well. That is, we have arrived at an expression for $\hat{y}_i$:

$$\hat{y}_i = \hat{a}_1 P_{1i} + \hat{a}_2 P_{2i} + \ldots + \hat{a}_n P_{ni} + \hat{b}_1 X_{1i} + \ldots + \hat{b}_k X_{ki}$$

where the $\hat{a}_i$'s are estimates of the process mix coefficients, the P_{ji}'s reflect the process mix fractions, and the $\hat{b}_k$'s and X_{ki}'s are estimated coefficients and the plant's own values for variables other than process mix, respectively.

Now consider what is called the *residual* value for plant *i*. The residual, r_i, is defined as the *actual* value for plant *i* minus its *predicted* value:

$$\begin{aligned} r_i &= y_i - \hat{y}_i \\ &= y_i - (\hat{a}_1 P_{1i} + \hat{a}_2 P_{2i} + \ldots + \hat{a}_n P_{ni} + \hat{b}_1 X_{1i} + \ldots + \hat{b}_k X_{ki}). \end{aligned}$$

Plants achieving lower-than-expected values will have negative residuals; those with higher-than-expected scores will have positive residuals. (Note that for our metrics, lower scores imply lower energy use or lower pollution. Thus, negative residuals imply better-than-expected values for a given process mix; positive residuals imply worse-than-expected values.)

Substantial variation will still remain in the companies' residual scores. Recall that the maximum percent of variance explained by process mix alone (that is, the maximum R^2 value) was 37%, for sludge. This implies that at least 60% or more of the variance will remain in the residuals. But, the residuals will have been stripped of the *average* influence of process mix (and any other factors we choose to include). Thus, the residuals are precisely the numbers we need to make valid plant-to-plant comparisons.

Chapter 2. Using the Survey Results

In Chapter 1, our purpose was to extract as much information as possible from the Benchmarking Survey data using standard statistical tools. In this chapter, we put that information to work.

The primary goal of this chapter is to rank the participants in the survey in terms of their environmental performance, so that we can draw some conclusions about:

- What factors lead to good performance
- What consequences good performance has on the bottom line.

To accomplish the ranking task, we make extensive use of the *adjustment formulas* developed in Chapter 1. The adjustment formulas allow us to take certain key facts about a company and use them to predict three environmental performance measures:

1. How much water we would expect the company to discharge per dollar of sales
2. How much sludge we would expect the company to generate per dollar of sales
3. How much electricity we would expect the company to use per dollar of sales.

We can then compare actual performance with our expectations. The better a company's actual performance is compared with its expected performance, the higher its rank.

We make these comparisons separately for each of the three environmental performance measures. We also rank the companies in terms of organic emissions per dollar of sales (without using an adjustment formula). We then combine these four rankings into an overall performance ranking.

To help us express the results of our analysis in a simple form, we divide the companies into three performance levels, the top, middle, and bottom performers, as determined from their overall ranking. We can then examine many other pieces of data that we asked in the survey to find out what separates the top performers from the others. We also evaluated what it costs to be a top performer, and found a surprising answer.

2.1 Analysis of Phase 1 Data—Ranking Environmental Performance

In this section, we generate the company rankings for each of the environmental performance measures.

We obtained the data used for the ranking from the 132 companies that responded to the Phase 1 survey. We were able to use information from all these companies to generate the results presented in Chapter 1. However, in Chapter 2, we had to be more selective. In cases where we had good water data from a company but missing or questionable sludge data, or good electricity data but poor water data, we could not generate an overall ranking score for the company.

Companies were omitted from the overall rankings for other reasons as well. Because we wanted to use the rankings to look for detailed differences in operating practices, we ranked only the companies for which we had good Phase 2 survey data.

We also found that we could not evaluate companies primarily engaged in hard chromium plating on the same footing as other companies. Hard chromium plating companies generate different types of wastes than most other finishing operations. Wastewater and wastewater treatment sludge represent the bulk of the wastes generated by most metal finishing companies. Many hard chromium plating companies operate zero discharge systems and do not generate wastewater treatment sludge. Instead, they generate wastes in other forms, such as spent plating solution, tank bottoms, spent stripper solutions, and chromium air emissions. We did not have data related to these types of wastes, and would not, in any case, have been able to compare them directly with the waste streams typical of other processes. Therefore, we omitted companies for which hard chromium plating accounted for more than 50% of sales.

In the end, we generated an overall ranking for 37 companies. We put the top 12 in the top performance tier, the next 13 in the middle tier, and the last 12 in the bottom tier, and calculated the average performance of each tier. Finally, we checked to see to what extent the overall rankings corresponded to the rankings on the individual performance measures.

With this framework in place, we will be ready to draw conclusions from the Phase 2 survey data in Section 2.2.

2.1.1 Wastewater Discharge Rate

A description of the adjustment formula for water discharge is given in Section 1.3.4.2, and the associated coefficients are given in Table 1-19. In Table 2-1, the formula is applied to one of the companies in the database.

Column A lists the process mix for company 149 in the Benchmarking Survey database, and column B reproduces the adjustment formula coefficient from Table 1-19 (coefficients have been rounded to two places for display). The last column is the product of the entries in columns A and B. The sum of the entries in the last column, in the “Total” row, is the predicted wastewater discharge rate, in gallons per dollar of sales, for company 149.

The actual normalized discharge rate reported by company 149 is 0.37 gal/$ sales. In other words, company 149 is discharging only (0.37/1.98) = 18.7% of what would be expected from its process mix. This result indicates very good environmental performance.

Table 2-1. Sample Calculation of Predicted Wastewater Discharge Rates

Metal Finishing Process*	A, % of sales	B, gal/$ sales	A x B, gal/$ sales
Zinc Plating	0	4.79	—
Nickel Plating	15	1.99	0.30
Decorative Chromium Plating	10	2.27	0.23
Electroless Nickel Plating	10	1.42	0.14
Anodizing	30	1.96	0.59
Hard Chromium Plating	0	0.20	—
Precious Metals Plating	0	4.06	—
Silver Plating	10	-0.05	-0.01
Other Plating	5	1.80	0.09
Other Coating	10	4.07	0.41
Other Metal Finishing	10	2.36	0.24
Total	**100**		**1.98**

* See Section 1.3.4.2 for a description of process categories.

2.1.2 Sludge Generation Rate and Recycle/Disposal Method

The adjustment formula for sludge was discussed in Section 1.3.4.3, and the associated coefficients are given in Table 1-20. In Table 2-2, the formula is applied to the sales data from company 149. In contrast to the adjustment formula for wastewater, the formula for sludge includes some market data as well as process mix. Otherwise, the calculation proceeds just as for wastewater, as given in Section 2.1.1.

However, when we set up the system for ranking companies for sludge generation, we decided to introduce an additional factor. For wastewater, we simply took the ratio of the actual to the expected discharge rate calculated as a percentage, and used that number as the basis for comparing companies for the ranking. We felt that applying the same procedure to sludge would miss an important consideration.

Table 2-2. Sample Calculation of Predicted Sludge Generation Rate

Metal Finishing Process*	A, % of sales	B, lb/$ sales	A x B, lb/$ sales
Zinc Plating (Barrel)	0	0.029	—
Zinc Plating (Rack)	0	0.012	—
Nickel Plating	15	0.003	0.0004
Decorative Chromium Plating	10	0.005	0.0005
Electroless Nickel Plating	10	-0.002	-0.0002
Anodizing	30	-0.012	-0.004
Hard Chromium Plating	0	0.003	—
Precious Metals Plating	0	-0.002	—
Silver Plating	10	0.007	0.0007
Other Plating	5	0.005	0.0002
Other Coating	10	0.079	0.0078
Other Metal Finishing	10	0.011	0.0012
Subtotal	***100***		***0.0074***
Automotive	5	0.017	**0.0009**
Fastener	0	0.037	—
Total			**0.0083**

* See Section 1.3.4.2 for a description of process categories.

A company has two basic options for minimizing the sludge waste stream from its operations. It can avoid generating the sludge in the first place, or it can send the sludge off-site for recycling. We can tell from the Phase 1 survey data the extent to which companies are relying on the recycling option, since we asked for both sludge generated and sludge sent to landfill. The difference between the two numbers tells us how much sludge was sent for recycling. Recycling is better than landfilling, but it still involves transportation of a hazardous waste, and additional resources are consumed in the recycling process. We felt that it would be inconsistent to treat both options as equivalent, since not generating the sludge (the “pollution prevention” approach) is clearly preferable from an overall environmental standpoint. Companies that have made progress in sludge reduction by putting more metal on parts and less into sludge should be recognized by our ranking system as performing at a higher level than companies who recycle. Those that recycle should, in turn, be recognized as performing at a level above that of companies that send their sludge to a landfill.

Because there is no one “right way” to build this consideration into our ranking system, we chose the following method. We weight the relative importance of reduction by recycling so that it is given half as much credit in the ranking system as reduction by pollution prevention. One way to justify this method is to compare it with the approach used in the Strategic Goals Program (SGP). Companies participating in the SGP are given credit for making progress on a set of environmental goals. Companies reducing their sludge waste stream by recycling are given credit for one goal (reducing waste sent to landfill), but companies reducing their sludge waste stream by pollution prevention are given credit for two goals (the previous, plus increasing their metals utilization rate). Our system is, in that sense, consistent with the SGP framework.

Details on the ranking calculations are presented in Section 2.1.5.

2.1.3 Electricity Use

The adjustment formula for electricity use was discussed in Section 1.3.4.4, and the associated coefficients are given in Table 1-22. The adjustment formula follows the same pattern as with water use and sludge generation. To find the expected electricity usage for a company if its process mix (in sales dollars) and its location are known, construct a table similar to Tables 2-1 and 2-2, but using the coefficients found in Table 1-22. A sample calculation for electricity may be found in Section 1.3.4.

2.1.4 Organic Emissions

As noted in Section 1.3.2.6, we found no apparent connection between organic emissions and process mix, or any other plausible shop characteristic. Therefore, we do not have an adjustment formula for this case to predict a shop's emissions. Either our data set is lacking, or we do not know what to look for. Nevertheless, we can still use organic emissions data to rank the shops, on the principle that any is bad and none is best. We, therefore, took the worst performer in the data set in terms of organic emissions per sales dollar. That value represents "100% of the worst known performance". We calculated organic emissions per sales dollar for each other company, and divided it by the worst value. We used this "percent of worst case" number to form our ranking for this performance measure.

For our data set, the highest value of organic emissions per sales dollar is 0.0064 lb/$ sales (company 37).

2.1.5 Finding the Rank

In the above sections, we outlined ways to compare actual and expected performance data to generate a ranking scheme for the companies in the data set. In this section, we write out the formulas explicitly, and discuss how to combine the rankings for each performance measure into an overall ranking.

2.1.5.1 Formulas for the Ranking Number

The formulas for deriving the ranking number from the expected and actual performance for three of the environmental performance measures (water, sludge, and electricity) are similar. The water and electricity ranking formulas are, in fact, identical. Sludge has an extra complication, as discussed Section 2.1.2.

First, we define the quantities common to all the formulas. We use:

- E to represent the expected value of the performance measure (for example, the result of applying Table 2-1 to a company's sales data to find its expected water discharge)
- A to represent the actual value for that performance measure
- R to represent the ranking number, expressed as a percent.

Then, for water or electricity, the ranking number is given by:

$$R = (E - A)/E \times 100\%$$

A company performing exactly as expected (A = E) would have an R value equal to 0%. A company with "perfect" environmental performance (A = 0 — for example, no water discharged) would have an R value of 100%. A company performing worse than expected would have a negative R.

Once ranking numbers have been found for each company, the companies can be listed in order of R, with the largest value of R on top. Thus, the top environmental performers will be at the top of the ranking list.

To find the ranking formula for sludge, we need one additional number. We use:

- L to represent the fraction of a company's sludge that is disposed as hazardous waste in a landfill.

Then, the ranking number for sludge is given in terms of L by:

$$R = [(E - A)/E] \times (1 - 0.5 \times L) \times 100\%$$

A company shifting from all land disposal (L = 1) to all recycling (L = 0) will improve its score by a factor of 2. It is also interesting to compare the effect of decreasing the amount of sludge generated with the effect of moving an equal amount from land-disposal to recycling. To verify that this formula has the desired behavior, we look at two cases of improvement.

Case 1: a company decreases the total amount of sludge by D pounds per dollar of sales, without changing L. Its new ranking number is found by substituting (A - D) in place of A. This increases the value of R by an amount equal to:

$$(D/E) \times (1 - 0.5 \times L)$$

Case 2: a company decreases the amount sent to the landfill by D, without changing A. (That is, D pounds of sludge per dollar of sales is now being recycled instead of being land-disposed.) The new fraction sent to the landfill will be equal to (L - D/A). Substituting the new fraction into the formula in place of the old L increases R by:

$$0.5 \times (D/E) \times [(E - A)/A]$$

The actual size of the change will depend on the specific values of A and L. But, in both cases, the factor multiplying D/E stays constant (L stays constant in Case 1, and A stays constant in Case 2). Thus, a small change in D will be half as effective in Case 2 as in Case 1, which is the desired outcome.

Also note that, as we can see from Case 2, the ranking number will decrease for companies performing worse than expected if they shift from landfilling to recycling. The ranking scheme can be further elaborated to eliminate this side effect, but we did not feel that the additional complication would significantly improve the model in practice.

2.1.5.2 Overall Ranking

There is, of course, no such thing as a completely neutral ranking system.

To define expected levels of performance in Chapter 1, we had to choose which key company characteristics to use in the adjustment formulas. Statistics can tell us how effective a characteristic is at discriminating between one pattern of resource use or waste generation and another, but cannot tell us when to stop looking for company characteristics to test.

To develop a ranking system in Chapter 2, we had to choose which performance measures were important. We can select ranking formulas to assign credit or penalty for actual performance on the environmental indicators for which we have data, but we can only state which features we want to reward or penalize. We cannot prove they are necessarily the best choices.

The points where we had to exercise some subjective judgment may not have been obvious unless we were careful to point them out. In the next task that we tackle in this section, the subjectivity is out in the open and unavoidable. The best we can do to justify our choices is to state our intentions explicitly, and to invite interested readers to use the framework presented here develop alternative schemes, if they would make more sense for other purposes.

We need to combine the individual rankings on the environmental performance measures into one overall ranking. Immediately, we are forced to ask: How can you combine different measures of environmental improvement equitably?

We could simply list the rankings for the individual performance measures and leave it at that, but that would not provide an adequate framework for the two major purposes of this survey (helping the SGP evaluate progress, and identifying best practices).

The identification of a “best practices” company cannot be done on a piecemeal basis. For example, what if a company were good at minimizing water discharge *because* it was less successful with sludge? A plant that could pipe sludge to a recycler next door might look good in some ranking systems. But common sense would indicate that pollution prevention should be rewarded more than a fortunate choice of neighbor.

Therefore, it is not enough to determine that Company A is a low water consumer, Company B is a very efficient user of electricity, and so on. We have to create a reasonable way to put the indicators together, if only to flag potential anomalies in the data. With that preamble, here is the method we have selected.

For simplicity, we will use a linear combination of the individual rankings to generate the overall ranking. The choices to be made in the context of a linear model are:

- How should we weight the contribution of each individual ranking?
- What numbers should we choose for the bottom and top of the scale?

The choice of weights involves real consequences. The choice is an explicit statement about the relative importance of different resources or effluent streams to the overall ranking. We assigned weights to the four rankings as given in Table 2-3.

As indicated above, some degree of subjective judgment is unavoidable. But the choice is consistent with the SGP framework, in the following sense: Both wastewater and sludge generation each affect two of the seven core environmental goals of the SGP. Electricity use and organic emissions affect only a single goal each.

The choice of scale is arbitrary, and can be set for convenience in calculations, or for psychological or aesthetic reasons. One may prefer a 1 to 10 scale, or a 0 to 100 scale, or a 200 to 800 scale, but it will make no difference to companies' places in the ranking, or to conclusions that are drawn about their performance.

One easy possibility for a scale would have been 0 to 100, in keeping with each of the individual scores. We decided against that, for psychological reasons. It seemed more in keeping with the spirit of the intended use of the rankings to make the "100" level difficult but achievable. However, for the individual rankings, 100% success at reducing water discharge would mean using no water at all. This may be attainable for certain closed-loop processes, but is not likely to be feasible in the foreseeable future for all plating operations. Even if it were still arguably a noble goal for water, it would be hard to adopt for all variables. Achieving 100% success at avoiding electricity use is a contradiction in terms for electroplaters. The possibility that an electricity-free metal finishing industry could somehow be environmentally beneficial seems remote.

Table 2-3. Weight Coefficients Used for Combining Rankings on Individual Environmental Performance Measures Into Overall Ranking

Ranking	Weight Coefficient in Percent
Wastewater discharge rate	30
Sludge generation rate (with recycle vs. disposal)	30
Electricity use	20
Organic emissions rate	20

We set the maximum possible score at a level of 133. The implicit idea is that companies that can get three-fourths of the way to that unrealistically ideal value deserved the "100" ranking. This procedure seems reasonably consistent with the benchmarking data set. The highest ranked company attained a level of 102.8 on this scale, suggesting that the 100 level can be exceeded, but only by the best.

Table 2-4 summarizes the individual and overall rankings for the 37 companies in the study described in Section 2.1. Some specific details about process and customer mix for each of these companies are listed in Appendix 2A at the end of this chapter.

As described earlier in this section, the rankings for the individual environmental performance measures can range as high as 100% (for zero discharge or use) through 0% (for performance exactly matching expected performance) and on down into an unbounded negative range (for performance worse than expected).

The overall ranking is derived by taking the weighted average of the four individual rankings (with the weight coefficients as given in Table 2-3). The weighted averages are then expressed on a scale with a theoretical maximum value of 133, as described above.

Table 2-4. Individual and Overall Rankings for the 37 Companies With Sufficient Data for Equitable Ranking

Company ID	Overall Ranking Score	Wastewater Discharge, %	Sludge Generation/Disposal, %	Electricity Use, %	Organic Emissions, %
Top 12					
4	102.8	87.4	100.0	4.5	100.0
58	91.6	41.2	100.0	47.6	83.9
73	86.5	37.0	100.0	18.8	100.0
127	76.3	76.6	19.0	42.7	100.0
69	72.7	49.5	53.0	19.5	99.5
59	64.7	56.9	23.7	21.7	100.0
53	60.6	56.1	39.9	0.5	82.6
126	60.2	23.6	34.6	38.5	100.0
23	59.9	56.8	20.9	8.2	100.0
98	57.8	-19.1	77.3	29.4	100.0
121	55.3	64.8	-23.9	45.9	100.0
21	53.0	78.3	-38.6	39.4	100.0
Average	***70.1***	***50.8***	***42.2***	***26.4***	***97.2***
Median	***62.7***	***56.4***	***37.2***	***25.6***	***100.0***
Middle 13					
65	44.2	-25.2	53.7	22.9	100.0
47	37.1	50.1	8.8	-49.1	100.0
107	34.8	79.5	-24.2	-35.5	100.0
146	27.4	81.5	-69.8	-6.3	91.7
72	24.7	-8.6	-1.7	10.1	98.1
116	17.4	53.1	0.0	-114.2	99.8
114	13.9	16.7	-50.9	16.6	86.8
52	12.4	-67.4	17.7	34.1	87.2
37	6.6	1.4	-6.8	32.3	0.6
136	3.0	29.2	41.7	-170.4	75.3
76	-3.4	-26.3	-49.3	0.7	100.0
42	-4.7	-4.6	0.0	-85.2	74.4
93	-10.3	-1.5	-44.0	-70.5	100.0
Average	***15.6***	***13.7***	***-9.6***	***-31.9***	***85.7***
Median	***13.9***	***1.4***	***-1.7***	***-6.3***	***98.1***
Bottom 12					
132	-23.5	-63.2	-54.8	-10.0	98.7
81	-29.9	48.6	-143.5	-69.6	100.0
36	-36.2	-3.2	-165.8	17.6	100.0
100	-43.4	-169.8	0.0	-2.0	94.1
6	-48.5	-34.1	-110.9	-64.5	100.0
67	-49.4	-41.2	-157.2	12.2	100.0
79	-49.5	-98.2	-61.1	-19.7	73.0
60	-54.6	-144.1	-3.7	-83.0	100.0
14	-55.7	-85.9	-121.2	1.7	100.0
44	-61.2	-38.9	-137.3	12.8	21.9
87	-62.9	15.0	-217.1	-32.5	100.0
39	-191.3	-108.2	-455.0	44.7	82.6
Average	***-58.8***	***-60.3***	***-135.6***	***-16.0***	***89.2***
Median	***-49.5***	***-52.2***	***-129.2***	***-6.0***	***100.0***

The equation for converting the individual rankings to the overall ranking is therefore given by:

$$R_0 = (0.30 \times R_1 + 0.30 \times R_2 + 0.20 \times R_3 + 0.20 \times R_4) \times 1.33$$

where:

R_0 = overall ranking
R_1 = wastewater discharge ranking
R_2 = sludge generation ranking
R_3 = electricity use ranking
R_4 = organic emissions ranking.

The companies have been divided into three tiers, as discussed in Section 2.1. We averaged each tier's scores separately for each of the four rankings, and for the overall ranking. A comparison of the average values for each of the tiers shows that the top overall performers are indeed the top performers in all of the individual measures as well. The middle tier is higher than the bottom tier on three of the four individual measures, and is roughly comparable in organic emissions (where we feel the data is least reliable of all the performance measures tabulated here).

Our ranking procedure appears to have generated a consistent and sensible analysis. On that basis, we offer it for use by companies interested in comparing their performance against the companies represented in the Benchmarking Survey.

2.2 Analysis of Phase 2 Data

With our ranking system in hand, we are ready to make use of the data collected during Phase 2 of the Benchmarking Survey.

We examine two major categories of data. One deals with management and shop floor practices. Although we do not address the topic of environmental management system design for metal finishing operations directly in this report, we feel that the findings of the Benchmarking Survey help lay the groundwork for a future effort in this area. The second category concerns pollution control costs. It contains the final, and perhaps the most valuable, set of results in the data analysis portion of the report.

2.2.1 Production and Environment-Related Practices

Several questions in the Phase 2 survey were intended to determine if certain production or environment-related practices affect environmental performance. The practices covered by the Phase 2 survey included eight categories of questions:

1. Management approaches
2. Training
3. Facility conditions and activities
4. Written procedures documenting workplace rules
5. Maintaining records
6. Energy savings practices or technologies
7. Pollution prevention practices
8. Industrial hygiene practices.

The questions were of several types. Some were yes/no responses, some were qualitative ratings (such as ratings on a scale from 1 to 5), and some were quantitative (such as numbers or percents). By their nature, the questions did not lend themselves to the type of quantitative treatment that we applied to resource use and waste generation measures. Instead, we were mainly interested in seeing which of the items were particularly strongly associated with top (or bottom) performers, as determined from the Phase 1 data.

The results are summarized in eight tables in the following sections. In each case, we averaged the responses from top, middle, and bottom performers separately. It is generally apparent from the tables which measures were associated with better environmental performance and which did not show any clear connection.

2.2.1.1 Management Approaches

We asked survey participants to indicate which of several management approaches apply to their facility. The approaches, and a summary of the responses received, are presented in Table 2-5.

Table 2-5. Management Approaches—Summary of Responses

Management Approach	% Yes per Tier		
	Top	Middle	Bottom
Organization of employees into work teams	33	46	33
Use of statistical process control	50	54	25
Implementation of a total quality management program	17	8	25
Working toward or achievement of ISO 9000 certification	67	38	50
Working toward or achievement of ISO 14000 certification	8	31	17
Average	**35**	**35**	**30**

We wanted to see if trends existed across the tiers. For example, would we find a consistent increase or decrease across the three tiers?

We concluded that the results do not suggest any conspicuous relationships among the management approaches used by survey respondents and their environmental performance.

Is this lack of obvious correspondence between management techniques and environmental performance a reflection of factors specific to the metal finishing industry? Does it tell us something about how the techniques are being applied in practice? Or instead, should we be investigating whether these fairly standard techniques are even relevant for typical metal finishing operations?

The Benchmarking Survey has raised these questions, but it would probably take a study focused specifically on management issues to provide definitive answers to them.

2.2.1.2 Training

Survey participants were asked how many metal finishing shop floor employees they had at the end of 1998, and to indicate how many of those employees had received formal training in the listed subject areas within the previous 3 years (1996 to 1998). The survey instructions indicated that they should only consider structured training programs, such as courses and workshops. Further, the instructions indicated that both programs conducted by outside trainers and any structured in-house training *should* be included, but that informal training done while workers carry out their usual day-to-day activities *should not* be included. A summary of the responses is presented in Table 2-6.

These results do not show a strong relationship between the use of training programs and environmental performance. One possible exception is training related to metal finishing principles and chemistry. However, because no other types of training, including pollution prevention, show any clear trends between tiers, it is possible that the trend observed for metal finishing principles and chemistry training is simply due to chance.

2.2.1.3 Facility Conditions and Activities

We looked for potential correlations between facility housekeeping activities and environmental performance. Participants were asked to indicate how well their facility is maintained for each condition or activity, on a scale of 1 to 5, where:

1 = Never
2 = Sometimes
3 = Often
4 = Almost Always
5 = Always.

Table 2-6. Training—Summary of Responses

Type of Training	% Employees Trained per Tier		
	Top	Middle	Bottom
Average number of metal finishing shop floor employees	54.6	54.5	84.9
Metal finishing principles and chemistry	54.6	8	28
Waste treatment / regulatory compliance	13	37	14
Hazardous material handling / spill response	20	45	22
Pollution prevention	20	42	12
Hazardous waste handling	22	32	24
Average	**20**	**33**	**20**

The results are summarized in Table 2-7. Overall, there was very little difference between the average responses among the three environmental performance tiers, suggesting that there is no correlation between facility conditions and environmental performance.

We noted that, overall, companies thought highly of the condition of their facilities. It is possible that most of the facilities responding to the survey are well maintained. However, it is also possible that some respondents were not completely objective when answering this particular question.

Table 2-7. Facility Conditions and Activities—Summary of Responses

Facility Condition and Activity	Average Score per Tier*		
	Top	Middle	Bottom
Little or no rust is visible on metal surfaces such as tanks, pipes, and equipment.	3.5	3.6	2.8
Shop floors are cleaned daily and are kept free of debris and are dry except for unusual situations.	3.8	3.9	3.9
The shop is maintained in an orderly fashion and the processing area is not cluttered with materials	4.1	4.0	3.8
Empty containers and packaging are immediately removed from the production area and recycled or discarded.	4.2	4.0	4.2
The metal finishing shop is maintained in a sufficiently attractive and safe condition that customers and/ or the general public could be given tours at any time.	4.2	4.0	4.1
The workplace is kept free of fumes and steam (may arise from hot process tanks).	4.6	4.0	4.0
The workplace is maintained at a comfortable temperature in both the winter and summer.	3.3	3.5	3.2
Process tanks are never idle for more than 6 months. Idle tanks are drained and the solution is recycled/treated/ disposed or properly stored.	4.5	4.8	4.8
Process and rinse tanks are kept free of floating oil and debris.	4.8	4.4	4.7
The worker's break room and/or locker room is kept in an orderly and clean condition.	4.1	4.2	4.3
Overall Average	**4.1**	**4.0**	**4.0**

* 1–never; 2–sometimes; 3–often; 4–almost always; 5–always

A possible trend exists between environmental performance and two of the facility condition/ activity factors: condition of tanks ("little or no rust") and quantity of fumes in the workplace ("free of fumes"). On the "little or no rust" question, companies in the upper and middle tiers averaged between "often" and "almost always," while companies in the lower tier averaged between "sometimes" and "often." On the "fumes" question, there was less distinction between the tiers, but the upper tier definitely averaged higher than the middle and lower tiers. Something that these two questions have in common is that older facilities are more likely to have maintenance problems associated with tanks and fumes (related to tank ventilation systems). Although the survey form did not cover age of facility, it may be a factor with regard to environmental performance.

2.2.1.4 Written Procedures Documenting Workplace Rules

Participants were asked:

- If they have formal, written procedures or documented workplace rules covering each of the listed areas
- If yes, to what extent their written procedures actually reflect the way they usually do things.

Participants used the following key to respond:

1 = No written procedures.

2 = Written procedures are out-of-date or inaccurate; they do not reflect our usual way of doing things.

3 = Written procedures reflect our usual and preferred practice; exceptions occur, and we do not rigidly monitor conformity.

4 = Written procedures reflect required practice: exceptions rarely occur and are cause for corrective action.

NA = Not applicable.

The results are summarized in Table 2-8.

Table 2-8. Written Procedures Documenting Workplace Rules—Summary of Responses

Written Procedure	Average Score per Tier*		
	Top	Middle	Bottom
Plating/finishing procedures	3.9	3.2	3.3
Bath quality/performance	3.9	3.8	3.5
Preventive maintenance	3.0	2.8	2.8
Waste treatment equipment operation/maintenance	3.5	3.4	3.6
Wastewater sampling	3.9	3.2	3.5
Hazardous waste management	3.8	3.5	3.5
Hazardous material handling/ spill response	3.7	3.5	3.7
Overall Average	**3.7**	**3.3**	**3.4**

* 1 – No written procedures

2 – Written procedures are out-of-date or inaccurate; they do not reflect our usual way of doing things

3 – Written procedures reflect our usual and preferred practice; exceptions occur, and we do not rigidly monitor conformity

4 – Written procedures reflect required practice: exceptions rarely occur and are cause for corrective action.

We are willing to admit a (somewhat faint) relationship between use of written procedures and environmental performance among survey participants. This relationship is born out by the overall averages and trends among certain individual questions. Comparing the top tier to the middle and bottom performance tiers, the most significant differences are found in use of written procedures for plating/finishing and wastewater sampling. There also is a slight trend with respect to hazardous waste management. However, due to the closeness of the responses, we cannot contend that this is a firmly established result.

2.2.1.5 Maintaining Records

Participants were asked:

- If they keep records for each item listed
- If yes, what purpose these records serve.

Participants used the following key to respond:

1 = No records are kept.

2 = Records are kept, but typically not used for any purpose (except perhaps to meet legal requirements).

3 = Records are kept. They are analyzed at least annually, but less than monthly, and used to improve performance.

4 = Records are kept. They are analyzed at least monthly, and used to improve performance.

NA = Not applicable.

The results are summarized in Table 2-9.

Table 2-9. Maintaining Records—Summary of Responses

Type of Records	Average Score per Tier*		
	Top	Middle	Bottom
Bath chemistry (analytical)	3.7	3.8	3.4
Bath chemical additions	3.6	3.8	3.5
Bath temperature	2.9	2.9	3.0
Rectifier use	2.0	2.4	2.8
Preventative maintenance logs	3.3	2.8	2.8
Rejects (misplated parts)	3.7	3.4	3.5
Customer returns	3.9	3.5	3.7
City water chemistry (e.g., hardness)	1.7	1.6	2.0
Units of production (number of parts, pounds, square feet, etc.)	3.1	2.9	2.9
Electricity use	2.8	3.2	3.3
Water use	3.5	3.4	3.5
Treatment sludge generation	3.1	3.2	3.3
Waste treatment chemical reagent use	3.3	3.0	3.6
Overall Average	**3.1**	**3.1**	**3.2**

* 1 = No records are kept.

2 = Records are kept, but typically not used for any purpose (except perhaps to meet legal requirements).

3 = Records are kept. They are analyzed at least annually, but less than monthly, and used to improve performance.

4 = Records are kept. They are analyzed at least monthly, and used to improve performance.

Overall, there was very little difference between the average responses among the three environmental performance tiers, suggesting that there is no correlation between record maintenance and environmental performance.

2.2.1.6 Energy Savings Practices or Technologies

Participants were asked if they use any of the listed energy-savings practices or technologies. The possible responses were yes and no. The results are summarized in Table 2-10. Overall, there was very little difference between the average responses among the three environmental performance tiers, suggesting that there is no correlation between energy savings approaches and environmental performance.

Because energy use is one of the specific performance measures used, we performed a separate analysis to determine if there was a relationship between use of energy savings approaches and the ranking for that specific performance metric. This analysis also did not show any correlations. The average implementation results from this separate analysis were:

- Lowest third electricity users: 23%
- Middle third electricity users: 34%
- Highest third electricity users: 32%.

2.2.1.7 Pollution Prevention Practices

Participants were asked if they performed or updated the listed pollution prevention items in the past three years. The possible responses were yes and no. The results are summarized in Table 2-11. There is a consistently strong correlation between implementation of the listed pollution prevention (P2) items and the environmental performance of the survey respondents. For nearly all of the items listed, a higher percentage of the top tier companies implemented the P2 items more than the middle tier and a higher percentage of the middle tier companies implemented the P2 items more than the bottom tier.

Of all the management practices we considered, implementing pollution prevention practices gave the most unequivocal result.

Table 2-10. Energy Saving Approaches—Summary of Responses

Energy Savings Practice or Technology	% Yes per Tier		
	Top	Middle	Bottom
Conducted an energy audit	50	31	67
A facility-wide peak demand control system	8	23	17
Heat recovery system (hot water, exhaust stack	17	23	25
Co-generation	8	0	0
Insulated hot process tanks	67	46	67
Overall Average	**35**	**25**	**30**

Table 2-11. Pollution Prevention Practices—Summary of Responses

Pollution Prevention Practice	% Yes per Tier		
	Top	Middle	Bottom
Conducted a P2 assessment	75	54	42
Prepared a process map of the facility operations	83	54	33
For each process step, identified raw material and energy inputs	42	38	17
For each process step, identified all outputs	75	38	25
Included auxiliary operations in the process map	67	54	25
Prioritized the waste streams by significance of their environmental impact	58	38	25
Established a system where all employees can generate, propose, and implement pollution prevention ideas	75	46	50
Investigated opportunities to substitute hazardous chemicals with non-hazardous or less hazardous chemicals	92	92	75
Implemented projects to substitute hazardous chemicals with non-hazardous or less hazardous chemicals	92	77	58
Overall Average	**73**	**55**	**39**

2.2.1.8 Industrial Hygiene Practices

Participants were asked if they had performed a set of items relating to industrial hygiene practices in the previous calendar year. The possible responses were yes and no.

The items and the results are summarized in Table 2-12. We saw little difference between the average responses among the companies responding to the survey. No correlation between implementing the industrial hygiene practices listed and the environmental performance of survey participants was apparent in our data.

2.2.2 Pollution Control Costs

The final piece of analysis of the survey data that we present in this report deals with the issue that is sure to get the greatest attention from those in the business of metal finishing: the relationship between environmental performance and costs.

The Phase 2 survey form collected data both on unit costs (cost per gallon of water discharged or pound of sludge disposed, for example) and on overall spending for environment-related expenses. The data from the 37 companies that form the three-tiered ranking system are collected in two tables presented below. We have computed average and median scores on a number of different cost indicators separately for companies in the top, middle, and bottom tiers of environmental performance.

Table 2-12. Industrial Hygiene Practices—Summary of Responses

Industrial Hygiene Practice	% Yes per Tier		
	Top	Middle	Bottom
Workplace air sampling is done regularly	33	23	42
Workplace sampling is done when complaints are received	83	100	75
Workers are provided with clothing (e.g., coveralls) that is laundered by your company on a regular basis	58	54	58
Conducted regular medical surveillance	42	15	33
Overall Average	**54**	**48**	**52**

Looking first at Table 2-13, we find that unit costs for environment-related expenses appear to have a marked impact on environmental performance. The table lists the average unit costs for water, sludge disposal, and electricity as reported by companies in each performance group.

Note that for this purpose, we used a performance grouping specific to the resource. In other words, the average water cost listed in Table 2-13 for the top performance group includes the companies that were the top performers specifically in the wastewater discharge category. The average cost for sludge for the top performance group is an average over the top performers specifically for sludge. The set of companies used for the water average may differ from the set used for the sludge average. (However, performance levels tended to be consistent across categories, so there is a lot of overlap.)

The trend is unmistakable. Where unit costs are highest, companies' environmental performance is also highest:

Table 2-13. Summary of Environmental Performance Versus Unit Cost Analysis

Performance Group (relative to specific metric)	**Average Water/Sewer Charge, \$/1,000 gal**[1] (average/median)	**Average Sludge Costs, \$/lb**[2] (weighted average/median)	**Average Electricity Cost, \$/kWh**[3] (average/median)
Top	4.65/4.92	0.22/0.23	0.095/0.094
Middle	4.13/3.71	0.24/0.22	0.076/0.070
Bottom	3.23/2.93	0.10/0.26	0.071/0.067

[1] Related criterion is wastewater discharge (Rank 1).

[2] Related criterion is sludge generation/disposal method (Rank 2).

[3] Related criterion is electricity use (Rank 3).

- Water use is least when water/sewer charges are highest.
- Sludge generation is lowest when transportation and disposal costs are highest.
- Electricity use is lowest when electricity unit costs are highest.

It stands to reason that the more a company pays for a resource or an environmental service, the greater will be its incentive to control its costs through better efficiency and cleaner operation. While it is reassuring to see this trend reflected in the data, it may not be particularly surprising.

The results shown in Table 2-14 may come as more of a surprise. We have listed the 37 ranked companies in three performance tiers (using overall performance rankings), and we have listed each company's actual environment-related spending, normalized per thousand sales dollars.

Despite the fact that the top-performing companies face higher unit costs on average, their overall environmental costs per sales dollar are *lower* than the costs for companies that do not perform as well. This seems to be true throughout the hierarchy. The middle performers spend less per sales dollar than the low performers on overall environmental costs. This trend holds true for most of the categories taken individually.

To see what difference this trend can make to the bottom line, we can use survey information to convert savings per sales dollar to total savings that an average shop might expect on the basis of these numbers if it were to improve to the level of a top performer.

When expressed as a percentage of total sales, the median total environmental operating cost is 7.0% of sales for top performers, 10.1% for middle performers, and 12.7% for bottom performers. These percentages have considerably more impact when translated to dollars. Consider the following:

- The median-size company in the middle performance tier has $3.57 million in annual sales (as can be determined from the data in Appendix 1B). If a company of this size improved its performance to the level of the median of the top tier, it would save $110,670 per year in environmental operating costs.
- The median-size company in the bottom performance tier has $6.35 million in annual sales. If a company of this size improved its performance to the level of the median of the top tier, it would save $361,950 per year in environmental operating costs.

This analysis does not take into account capital costs. Certainly, companies in the top tier have invested capital to achieve the savings they are enjoying. Each company will have to assess its own situation to determine when such investments can be justified. But the results found here indicate the potential for a significant rate of return for environment-related capital expenditures. If noble sentiments are not sufficient to convince metal finishers to take a good look at pollution prevention opportunities, perhaps these results are.

Table 2-14. Environment-Related Spending for the Three Performance Tiers

Company ID	Overall Phase 1 Rank (Based on 74 Companies)	Water/ Sewer Costs, $/$1,000 Sales	Electricity Costs, $/$1,000 Sales	Waste Costs, $/$1,000 Sales	Environment Labor Costs, $/$1,000 Sales (at $20/hr loaded)	Total Environment Operating Costs $/$1,000 Sales
Top Tier						
4	1	1.65	23.75	4.03	6.62	36.05
58	2	5.34	5.74	26.21	16.72	54.00
73	4	17.60		80.97	96.97	
127	7	7.56	34.09	23.14	60.22	125.01
69	9	4.41	19.62	8.37	15.57	47.96
59	11			56.29	49.12	
53	14	5.90	26.16	44.77	69.07	145.89
126	15	12.82	21.69	25.56	15.75	75.81
23	16	11.06	31.55	49.25	36.19	128.05
98	18	22.65	23.38	8.44	15.05	69.52
121	19	1.93		10.15	16.64	
21	20	2.81	24.27	13.59	28.65	69.31
Average	***11.3***	***8.52***	***23.36***	***29.23***	***35.55***	***83.51***
Median	***12.5***	***5.90***	***23.75***	***24.35***	***22.68***	***69.52***
Middle Tier						
65	25	13.83	19.22	14.26	23.88	71.18
47	28			46.52	50.71	
107	30	4.62	49.01	21.32	36.76	111.71
146	34			20.53	5.79	
72	35	12.52	27.56	47.06	35.69	122.83
116	41	2.03	44.66	8.62	16.32	71.62
114	43	20.05	41.16	10.52	29.14	100.87
52	44	16.06	18.06	47.12	33.72	114.97
37	49	23.77	30.04	21.19	12.90	87.90
136	51	2.64	27.36	20.37	26.62	76.99
76	52				16.24	
42	53	7.50	74.67	6.25	20.42	108.83
93	55				21.01	
Average	***41.5***	***11.45***	***36.86***	***23.98***	***25.32***	***96.32***
Median	***43.0***	***12.52***	***30.04***	***20.53***	***23.88***	***100.87***
Bottom Tier						
132	58	12.92	21.41	16.59	20.64	71.56
81	60	5.96	36.87	77.55	21.07	141.46
36	61	13.42	31.64	50.97	20.39	116.42
100	62	14.41	20.37	3.07	1.25	39.10
6	64	12.77	83.19	57.75	68.09	221.79
67	65	11.43	28.29	46.33	41.02	127.06
79	66	30.48	24.74	22.53	11.87	89.62
60	68	54.36	43.74	70.07	55.28	223.44
14	69	16.66	40.85	46.32	76.97	180.80
44	70	7.78	22.76	27.56	4.92	63.02
87	71	11.85	40.44		34.23	
39	74	8.81		30.56	7.41	
Average	***65.7***	***16.74***	***35.84***	***40.84***	***30.26***	***133.63***
Median	***65.5***	***12.84***	***31.64***	***38.44***	***20.86***	***127.06***

Appendix 2A: Descriptive Data for Ranked Companies

To provide a more colorful picture of the environmental performance data, we have prepared three tables with some of the descriptive information from Appendix 1B, arranged by company ranking as developed in Chapter 2. By scanning these tables, readers can get an idea of what types of companies have managed to achieve superior performance.

Perhaps the most encouraging pattern in these tables is the lack of pattern. In general, top performers have not achieved that position simply because they concentrate on certain processes or because they deal in markets in which they can demand higher prices from their customers (thus decreasing measures per sales dollar). Zinc platers are represented both in the top and in the bottom tier. So are decorative chrome platers. Suppliers to the motor vehicle industry are also represented at all levels. There are a few exceptions. Perhaps not surprisingly, precious metals platers tend to look good in this ranking. But by and large, it would appear that good environmental performance is attainable by a broad spectrum of companies, should they choose to make that commitment.

The keys to the abbreviations used in the three tables are given below.

Key 1: Customers

Abbreviation	Customer
Aero	Aerospace/Aircraft
Bldg	Building/Construction
Boat	Boats/Ships
El, oth	Other Electronics
Fast	Fasteners
Furn	Furniture
Hdwr	Hardware/Tools
Hd, oth	Other Hardware
Hshld	Household Appliances
Jewel	Jewelry/Watches
Mach	Machinery/Industrial
Med	Medical
Mil	Military/Government
MotV	Motor Vehicles
Other	Other
Plmb	Plumbing Fixtures
PWB	Printed Wiring Boards
RR	Railroad
Sport	Sporting Goods/Toys
Wire	Wire Goods and Pipes

Key 2: Process Mix

Abbreviation	Process
Ag	Silver Plating
An, Cr	Anodizing (Chromic Acid)
Anod	Anodizing (Sulfuric Acid)
BlOx	Black Oxide
Brass	Brass Plating
Brnz	Bronze Plating
Cd	Cadmium Plating
ChMl	Chemical Milling
CrO^3	Chromating
Cu	Copper Plating
D Cr	Decorative Chromium Plating (Includes Cu, Ni Layers)
EN	Electroless Nickel Plating
EPol	Electropolish
H Cr	Hard Chromium Plating
Ni	Nickel Plating
Other	Small, Unspecified Process
Paint	Painting
Pass	Passivation
Phos	Phosphating
Prec	Precious Metals Plating, Except Silver
Tin	Tin Plating
TinPb	Tin–Lead Plating
Zn	Zinc Electroplating

Table 2A-1. Top Tier

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)
4	2.7	Boat 1 Hd, oth 9 Mach 28 Med 15 MotV 10 Plmb 28	D Cr 77.6 EN 4.6 EPol 17.8
58	8.3	Aero 1 Boat 2 El, oth 3 Fast 1 Hdwr 3 Hshld 2 Mach 70 Med 2 Mil 3 MotV 10 RR 1 Sport 1 Other 1	Anod 45 BlOx 9 CrO_3 10 EN 27 Zn 5 Other 4
73	0.8	Aero 5 Hdwr 20 Mil 15 MotV 20 Sport 20 Wire 20	Cd 8 Phos 14 Zn 69 Other 9
127	1.8	Aero 10 Bldg 10 Fast 30 Furn 10 Hdwr 3 MotV 10 Plmb 5 RR 5 Wire 5 Other 12	BlOx 10.1 Brass 10.2 Ni 10.0 Zn 69.7
69	23.0	Aero 10 El, oth 50 Med 2 Mil 8 MotV 22 PWB 8	Ag 20 Cu 2 Ni 3 Prec 50 Tin 15 TinPb 10
59	0.6	Bldg 5 Fast 5 Hdwr 10 Mach 10 MotV 25 Wire 20 Other 25	BlOx 10 Ni 35 Pass 9 Zn 43 Other 3
53	3.4	Aero 80 El, oth 20	Anod 17 An, Cr 16 Cd 9 EN 15 Paint 7 Pass 3 Prec 9 Ni 5 Zn 7 Other 12
126	3.0	El, oth 30 Fast 10 Hshld 10 MotV 50	Ag 10 Prec 5 Ni 14 Tin 50 Zn 20 Other 1
23	6.6	Bldg 40 El, oth 7 Fast 3 Furn 7 MotV 40 Wire 3	Zn 100
98	6.8	Fast 60 Hshld 5 Mach 5 MotV 30	Zn 100
121	10.0	Aero 60 Furn 3 Hdwr 5 MotV 2 Plmb 10 Other 20	Ag 6 Brass 6 Brnz 6 Cu 6 D Cr 25 Prec 40 Ni 6 Other 5
21	3.2	El, oth 85 MotV 15	EN 26 Zn 74

Table 2A-2. Middle Tier

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)	Process Mix, % of sales (see Key 2)
65	6.4	Fast 35 Mach 1 MotV 15 Hdwr 15 Mil 2 Sport 2 Hshld 30	BlOx 5 Zn 34 Phos 59 Other 2
47	4.4	Bldg 1 Hshld 7 MotV 2 Fast 5 Hs, oth 10 Plmb 4 Furn 3 Mach 52 Sport 2 Hdwr 10 Mil 2 Wire 2	BlOx 5 Phos 5 D Cr 12 Zn 65 EN 4 Other 4 Ni 5
107	3.5	Aero 15 Hdwr 3 Mil 2 Bldg 2 Hs, oth 3 MotV 3 El, oth 40 Jewel 2 Sport 2 Fast 4 Mach 15 Wire 4 Furn 3 Med 2	Anod 15 Ni 5 Cd 5 Prec 5 CrO_3 10 Tin 5 EN 5 Zn 50
146	3.0	Aero 50 Med 2 El, oth 10 Mil 25 Fast 5 Sport 1 Mach 5 Wire 2	Ag 6.0 Paint 0.8 Cd 23.0 Pass 6.0 EN 31.0 Tin 2.0 EPol 13.0 Other 12.2 Ni 6.0
72	3.3	Aero 15 Mach 25 MotV 25 Bldg 5 Mil 20 Wire 5 Hshld 5	Anod 23 Zn 59 Tin 4 Other 14
116	0.6	Aero 5 Mach 66 El, oth 10 Mil 19	EN 100
114	3.0	Bldg 20 MotV 20 Fast 40 Wire 20	Phos 7 Other 5 Zn 88
52	3.4	Aero 5 Hdwr 20 MotV 5 Fast 5 Hshld 20 Wire 15 Furn 15 Mach 15	BlOx 8 Phos 8 Cu 7 Zn 36 D Cr 33 Other 8
37	3.6	Bldg 5 Hs, oth 5 Sport 10 Fast 50 MotV 10 Wire 10 Hdwr 10	Zn 95 Other 5
136	3.7	Aero 20 Med 5 El, oth 5 Mil 10 Mach 20 MotV 40	EN 60 Phos 25 Paint 5 Other 2 Pass 8
76	27.1	El, oth 4 Mil 1 MotV 95	Ni 95 Prec 5
42	3.6	Aero 5 Hdwr 1 Mil 6 Bldg 8 Hs, oth 6 MotV 15 Boat 3 Mach 28 RR 1 El, oth 5 Med 6 Other 15 Fast 1	Anod 92 Paint 6 Other 2
93	3.9	Bldg 10 Hs, oth 5 Sport 10 Fast 15 Mach 5 Wire 5 Hdwr 5 MotV 30 Other 10 Hshld 5	Anod 14 Cu 9 Phos 5 Zn 72

Table 2A-3. Bottom Tier

ID	Annual Sales, millions of dollars	Customers, % of sales (see Key 1)		Process Mix, % of sales (see Key 2)	
132	12.1	Bldg 20 El, oth 5 Fast 2 Furn 2	Hdwr 5 Mil 1 MotV 61 Other 4	Anod 10 Cd 8.3 D Cr 38.4	H Cr 16.7 Prec 13.3 Zn 13.3
81	4.8	Bldg 5 Fast 88 Furn 1	Hs, oth 1 Plmb 1 Other 4	CrO_3 9 Pass 13	Phos 35 Zn 43
36	7.3	Bldg 5 El, oth 10 Fast 5 Hs, oth 15	Mach 15 MotV 30 Wire 20	Phos 7 Zn 89 Other 4	
100	27.0	no data		Anod 65 CrO_3 5	EN 30
6	0.2	Other 100		D Cr 100	
67	3.8	Boat 5 El, oth 25 Fast 5 Hdwr 10 Hshld 5	Hs, oth 20 Mach 5 Med 20 Plmb 5	Cu 10 D Cr 10 EPol 10	Ni 66 Other 4
79	19.4	MotV 100		EPol 38 Phos 10	Zn 52
60	3.6	Bldg 5 El, oth 54 Fast 2 Furn 2	Hs, oth 2 Mach 2 MotV 27 Wire 6	Zn 97 Other 3	
14	2.2	Furn 25 Hdwr 10 Med 10	Wire 25 Other 30	D Cr 40 EPol 30 Zn 30	
44	10.0	Furn 10 Hdwr 5 Hs, oth 40	Mach 10 MotV 30 Wire 5	Brass 14 D Cr 42 EN 15 Zn 5	Ni 17 Paint 5 Other 2
87	7.9	Fast 1	MotV 99	Anod 27	Zn 73
39	5.4	Aero 15 El, oth 50 Fast 5 Hdwr 5	Mach 10 Med 5 Mil 5 Wire 5	Cd 7 Cu 44 EN 10	Ni 13 Zn 23 Other 3

Chapter 3. Guide to Best Practices

Many of the pollution prevention (P2) practices for this chapter of the report were suggested by Benchmarking Survey participants in their survey responses. We have supplemented this material with additional practices identified from:

- *Pollution Prevention and Control Technology for Plating Operations*, a document prepared by NCMS and the National Association of Metal Finishers (NAMF)[1]
- *P2 Concepts and Practices for Metal Plating and Finishing*, a course developed by the American Electroplaters and Surface Finishers Society (AESF) and the Environmental Protection Agency (EPA).[2]

For ease of use, we present the information in a process-by-process format. Certain key types of pollution control measures, such as those relating to water use reduction or bath maintenance, can occur in many different processes. Typically, different variants of each measure are appropriate for different processes, so they are discussed separately for each process. Here, we have included them under subheadings to assist readers who are seeking help with specific issues.

A glossary of terms is included at the end of this chapter in Appendix 3A. Terms in ***bold italics*** in the text are listed in the glossary.

A table at the end of each section summarizes the main recommendations. The "Objectives and Strategy" column lists important areas of general concern and offers strategies for reaching these objectives, which are:

- Reducing drag-out and water use
- Improving material utilization
- Reducing human exposure.

The "Potential Practices" column lists specific actions that companies may take with respect to the particular process under discussion. These actions are divided into two categories, basic and advanced. Actions in the advanced category typically involve somewhat greater effort and expense than do the actions in the basic category.

We invite companies seeking to improve their environmental performance to use this information to identify practices and process improvements that can work in their operations, and to map out a comprehensive pollution prevention strategy.

Please note: many considerations and trade-offs are involved in selecting the right strategy. This chapter includes many observations and suggestions submitted by survey respondents. Within the following text, the numbers in parentheses represent the arbitrary identification number assigned to respondents. Readers may use the information in Appendix 1B, Table 1B-1, for additional information about the referenced companies.

Some of the participants' suggestions are quite innovative. We have learned of the final, successful outcomes. What we cannot know is the degree of effort, the false starts and blind alleys, and the moments of insight that went into making them succeed. There are significant rewards for successful pollution prevention, as the data in the previous chapter indicate. But progress is seldom effortless. **Readers should fully investigate and evaluate any methods or technologies before implementing them.**

[1] Cushnie, George. *Pollution Prevention and Control Technology for Plating Operations.* National Center for Manufacturing Sciences, Ann Arbor, MI. 1994.

[2] American Electroplaters and Surface Finishers Society. *Pollution Prevention (P2) Concepts & Practices for Metal Plating & Finishing.* AESF, Orlando, FL. 1997.

3.1 Alkaline Cleaning

Alkaline cleaning is typically the initial operation performed on the plating line. It is also the first line of defense in the battle against two very significant causes of increased pollution from metal finishing operations: rejects (and consequent rework) and contamination of process solutions. This factor makes it all the more important that the alkaline cleaning process is working properly.

Although proper cleaning can help prevent pollution, the alkaline cleaning baths and associated rinses can themselves be significant sources of pollution. Cleaning baths are the most frequently discarded process solutions on most finishing lines. Spent cleaners and rinse waters, typically treated on site, generate significant quantities of sludge. Also, certain components of cleaners interfere with the precipitation of metals and, therefore, can affect compliance with discharge regulations.

Table 3-1 summarizes the following discussion regarding pollution prevention strategies for alkaline cleaning.

3.1.1 Alternatives to Solvent Cleaning

Alkaline cleaning is itself a pollution prevention technology, because it provides an alternative to solvent cleaning. As recently as 1980, 53% of metal finishing shops relied on chlorinated solvent cleaning to remove oil and grease from the parts prior to plating. The total quantity of solvent use by this industry sector dropped by 50% or more from 1986 to 1993, due in part to new regulations limiting the types of solvents that could be used, and in part to increasing costs for solvent. By 1993, only 32% of all shops were using solvent (see footnote 1, page 3-1). The data from the Benchmarking Survey suggest that solvent use has continued to decline. Only 23% of survey respondents indicated that they used solvents in 1998.

Respondents most commonly reported trichloroethylene (TCE) and methyl ethyl ketone (MEK) among the organic solvents still in use. Some companies have replaced chlorinated solvents with non-aqueous substitutes such as mineral spirits or emulsion cleaners. One respondent (89) indicated that the company switched to

Table 3-1. Summary of Pollution Prevention Strategy for Alkaline Cleaning

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out to the maximum extent possible, control rinse water use, and implement reactive rinsing.	Basic: • Reduce drag-out to decrease water use. • Install two-stage counterflow rinse tanks. Advanced: • Reuse acid rinse water for rinsing after alkaline cleaning. • Install conductivity, pH, or timer controllers. • Implement closed-loop rinsing with drag-out tanks and a microfiltration system.
Improve Material Utilization *Strategy:* Monitor the bath and make timely chemical additions. Maximize bath life/minimize solution disposal by removing bath contamination and using available maintenance technology. Avoid commingling alkaline cleaner wastes with other waste streams.	Basic: • Monitor bath for alkalinity and make timely additions. • Employ filtration and oil-removal technology (oil separator/skimmer). • Segregate cleaner waste streams from other wastes to improve wastewater treatment results. Advanced: • Monitor bath for individual bath components and make timely additions. • Use advanced bath maintenance technology (e.g., microfiltration) to keep contaminants at low levels and recycle drag-out with closed-loop rinse system.
Reduce Human Exposure *Strategy:* Eliminate use of solvents and cyanide.	Basic: • Convert solvent cleaning operations to alkaline cleaning. • Eliminate use of cyanide-bearing cleaners. Advanced: • None identified.

acetone because its regulatory status was changed to a non-volatile organic compound (non-VOC) listing.

3.1.2 Process Characteristics

The majority of finishers now rely solely on alkaline cleaning. Typically, this process is accomplished in two stages using a soak clean followed by an electroclean and rinse**.**

Cyanide is used in the formulation of some alkaline cleaners; however, its use has declined significantly over the past 20 years. Several survey respondents indicated that they had recently eliminated use of cyanide cleaners as a P2 measure (59, 65, 89, 129). One of these companies (89) indicated it uses bead blasters to supplement alkaline cleaning and, although this process is less efficient than the old process, it has eliminated use of cyanide-containing cleaners.

In addition to the substitution efforts described above, pollution prevention efforts by Benchmarking Survey respondents focused on two aspects of alkaline cleaning: rinsing and ***bath maintenance***.

3.1.3 Water Use Reduction

Good rinsing is an important aspect of plating. When parts emerge from a chemical process tank they are covered with a thin film of process solution, called ***drag-out***. Rinsing is used between process steps to remove the drag-out and prevent it from carrying over to the next chemical process tank. Since higher drag-out rates result in higher rinse water use, reducing the quantity of drag-out is a logical method of reducing rinse water use.

In addition to increasing rinse water use, excessive drag-out is costly because it results in the need for frequent additions of cleaner and increases wastewater treatment costs. Efforts to reduce drag-out by Benchmarking Survey respondents focused on:

- Rack or barrel design
- Part orientation
- Dwell times (12, 133)
- Rotating barrels over process tank (98)
- Use of ***spray rinsing*** of parts as they emerge from the soak cleaner (124).

Typically, a two-stage ***counterflow rinsing*** configuration following alkaline cleaning will be adequate. But survey participants reported a variety of alternatives:

- One respondent (124) indicated the use of a three-stage rinse system plus manual spray rinsing of parts after they emerge from each tank.
- Some companies (67, 97, 98) employ ***recovery rinsing***. One respondent (57) employs auto-activated spray headers to rinse the parts as they exit the cleaners to reduce drag-out and replace evaporated water. The headers only spray during the lift cycle (split-rail return-type line). This respondent suggested using low-flow nozzles (0.2 gpm) and pressure-reducing valves to control water flow.
- ***Reactive rinsing*** can be used where the rinse following acid dip is reused in the rinse tank following the alkaline cleaner (14, 73). The acidic rinse helps to remove the alkaline cleaner film better than plain water. However, two survey respondents (43, 67) warned that use of reactive rinsing could result in precipitated solids in the rinse water. Another respondent (60) indicated that precipitation of solids can be avoided by using a non-silicated cleaner.

Additional methods are available for regulating the rate of water use. They are applicable to any rinse configuration:

- ***Conductivity controls*** or pH controllers can control rinse water use.
- ***Timer rinse controls*** can also be employed (4).

One survey respondent (37) uses effluent from its wastewater treatment system for rinsing after alkaline cleaning and acid dip. This practice has cut the company's overall water use by 50%.

Another respondent (121) suggests using softened water when formulating the alkaline cleaning bath and when replacing evaporative losses. This company indicated that softened water extends the life of its cleaners and improves the cleaning process.

In general, when recovery rinsing is used, softened or deionized water should be used for rinsing.

3.1.4 Bath Maintenance

Bath maintenance is an important aspect of P2 and cost management, since it improves the performance of the alkaline cleaning operation, which, in turn, reduces reject and rework and extends the life of the bath. Maintenance includes chemical monitoring and timely additions of fresh chemicals as well as the use of various technologies to remove contaminants.

Most finishers limit their analysis of the alkaline cleaner bath to a single component such as alkalinity or conductivity (65). When the alkalinity drops below the recommended operating level, they add cleaner solution. But this practice fails to take into account that the specific components of the cleaning bath are usually degraded or consumed at different rates. A single test will not provide sufficient information.

Several survey respondents (60, 73, 12) indicated that they have implemented programs with more frequent bath analyses and that they analyze and subsequently adjust for individual bath components. One respondent (12) analyzes cleaners once every 8-hour shift. A different respondent (79) indicated that it has also increased analytical work to include contaminants such as oil and grease. This company uses these results to trigger bath disposal instead of routinely disposing of the solution based on a time schedule or amount of surface area processed.

Alkaline cleaner bath maintenance technologies are primarily used to remove suspended solids and oil. Large solids are removed by ***filtration***. Oil can be partially removed using an oil separator/skimmer (52, 59, 79, 98) or coalescer (58). These methods work best with cleaner chemistries that are formulated to "split" oils. One survey respondent (147) adds a reagent to used cleaners that helps split emulsified oil. The oil layer is subsequently skimmed and the cleaner is returned to service. Another respondent (68) constructed its own skimmer, which is used to recover honing oil.

Colloidal solids and oil can be removed by ***microfiltration***. Several survey respondents (65, 93, 97, 102, 127) employ this technology, including one respondent that is using microfiltration in a testing mode. When implementing microfiltration technology it is sometimes necessary to change cleaning chemistry. Microfiltration works best with non-silicated emulsifying cleaners.

One survey respondent (114) suggested that the soil-loading rate can be reduced by requiring customers to do some pre-cleaning before shipping their parts to the metal finisher.

Another approach to cleaner maintenance is the use of a ***microbial cleaner***. This technology appears to have gained favor among some of the respondents (76, 79, 136). This technology uses a specially formulated cleaner chemistry (approximately neutral pH), which permits the buildup of a microbial population that consumes oil and grease. One respondent (79) indicated that it uses a microbial cleaner on one production line with good results, and plans to use it in all similar processes.

Survey respondents identified some approaches to pollution reduction. One (97) company has achieved a ***closed-loop*** cleaning operation by using multiple ***drag-out tanks*** in a counterflow arrangement and a microfiltration system that processes both the bath and recovery rinse. (As noted above, softened or deionized water should be used in recovery rinse systems.) Closing the loop has an additional advantage. The cleaning solution chemistry includes chelating compounds such as EDTA that can interfere with metals precipitation. By closing the loop, finishers can minimize treatment problems caused by the chelating compounds.

Another company (43) indicated that it reuses two-thirds of its used electrocleaner as makeup for its soak cleaner and, therefore, only uses fresh chemistry in the electrocleaner tank. Electrocleaner baths are more concentrated than soak cleaners due to the need for electrical conductivity. When spent, this company's electrocleaner has a sufficient concentration of components to be reusable as a soak clean. However, some fresh solution must also be added. It should be noted that, as one survey respondent (53) pointed out, some electrocleaners do not work well as soak cleaners due to different chemistries.

Another company (124) indicated that it segregates rinse waters from alkaline and acid cleaning to prevent commingling with plating rinse waters. This can improve wastewater treatment results and decrease the cost of treatment.

One survey respondent (98) suggested switching from powdered cleaners to liquid cleaners; conductivity sensors and automatic feeders can be used with liquid cleaners to maintain the bath at the proper operating concentration. Another respondent (121) also recommends the switch because powdered cleaners may not completely dissolve in the bath, causing chemical waste and carryover of chemicals to the treatment system or sewer.

3.2 Acid Dipping and Pickling

Acid dipping is employed in most metal finishing shops to remove surface oxides and activate the surface of parts prior to plating. Acid pickling refers to processes aimed at removal of scale, a surface oxide that is formed when metal, such as steel, is cooled during the transformation from a molten metal into its solid form.

The most significant waste products generated from acid dipping and pickling are:

- Spent solutions
- Rinse water
- Wastewater treatment sludge
- Acid fumes
- ***Scrubber*** water blow-down.

Pollution prevention and control efforts for these processes should be aimed at process changes that reduce pollution and worker hazards, rinsing considerations, ***bath maintenance***/recovery methods, and other waste reduction opportunities.

Table 3-2 summarizes the following discussion regarding pollution prevention strategies for acid dipping and pickling.

3.2.1 Water Use Reduction

Excess water introduced by drag-in can dilute acid baths, especially if they are operated at ambient temperatures. Excessive ***drag-out*** is costly due to increased rinse water use, more frequent acid replacement, and increased wastewater treatment costs. To reduce drag-in and drag-out, efforts should focus on:

- Rack design
- Part orientation
- Dwell times.

Conductivity controls or pH controllers can control rinse water use. Commonly accepted ranges are pH 5–6 or a conductivity of 400–1,000 μmho. ***Timer rinse controls*** can also be used (12).

Typically, a two-stage ***counterflow rinsing*** configuration will suffice following acid dipping or pickling. Some survey respondents (14, 59, 79), use ***reactive rinsing***, where the rinse following

Table 3-2. Summary of Pollution Prevention Strategy for Acid Dipping and Pickling

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out to the maximum extent possible, control rinse water use, and implement reactive rinsing.	Basic: • Reduce drag-in to avoid diluting acid bath. • Reduce drag-out to decrease water use. • Install two-stage counterflow rinse tanks. Advanced: • Reuse acid rinse water for rinsing after alkaline cleaning. • Install conductivity, pH, or timer controllers. • Raise bath temperature and lower bath concentration to reduce chemical loss.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and using available maintenance technology. Recycle waste water treatment (WWT) sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize corrosion of busing, racks, fixtures, and parts; and retrieve parts or fixtures that fall into the bath). • Use the lowest possible acid concentration and temperature to reduce the attack on base metals. • Use inhibitors in pickling baths to reduce the attack of acid on base metals. • Recycle WWT sludge off-site. Advanced: • Filter acid solution to remove suspended contaminants. • Use bath maintenance technology (e.g., acid sorption or diffusion dialysis technology) to keep metallic contaminants at low levels.
Reduce Human Exposure *Strategy:* Minimize acid air emissions to workplace and community. Use less-toxic, substitute technologies, where applicable	Basic: • Employ adequate air speeds and ventilation rates to ensure removal of fumes or mists from inhalation zones. • Monitor inhalation zones to evaluate exposure and immediately correct any inadequacies. • Lower bath temperature and acid concentration to reduce hazard to employees. Advanced: • Consider use of alternative chemicals such as acid salts.

acid dip is reused in the rinse tank following the alkaline cleaner, as noted in Section 3.1.3. The acidic rinse helps to remove the alkaline cleaner better than plain water. However, two survey respondents (43, 67) warned that use of reactive rinsing could result in precipitated solids in the rinse water. One survey respondent (12) employs ***drag-in/drag-out recovery rinsing*** and reports that it conserves acid.

One survey respondent (37) uses effluent from its wastewater treatment system for rinsing after acid dip and alkaline cleaning. This practice has cut the company's overall water use by 50%.

3.2.2 Bath Maintenance

Bath monitoring and timely additions will improve performance and reduce waste generation (73). The efficiency of baths can be measured by a weight loss test. Acid baths are commonly contaminated with soils and dissolved metals, both of which reduce performance. ***Filtration*** is commonly used for removing particles (52, 81, 132). Dissolved metals can be removed by ***acid sorption*** and ***diffusion dialysis***. These technologies are generally not cost effective for small operations. Several survey respondents use acid bath maintenance. ***Electrowinning*** can be used for removing copper and zinc from dilute sulfuric baths (10% by volume).

3.2.3 Process Conditions

Higher concentrations of acid and higher operating temperatures dissolve more of the substrate metal. Since dissolved metal will cause the bath to lose effectiveness, lower acid concentrations and lower bath temperatures are preferred from a P2 standpoint. The less metal that is dissolved into the bath, the longer the life span of the solution. In addition, higher operating temperatures require use of energy, which is also a source of pollution. However, lower is not always better. Lower temperatures and acid concentrations increase the time necessary for pickling and oxide removal, and the finisher must consider the time constraints of the process. There is usually an operating range in which both time constraints and P2 objectives can be met.

3.2.4 Inhibitors

Inhibitors can be added to pickling baths to retard or stop the etching caused by the acid solution, thus providing a P2 benefit. Synthetic inhibitors made up of organic compounds are in common use today with pickling operations. As may be expected, the use of inhibitors increases the time needed to remove scale. When the concentration of inhibitor is increased, less base metal is dissolved and the required processing time increases, especially when low-concentration acids are employed. Yet P2 favors lower acid concentrations. The metal finisher must be prepared to deal with this trade-off.

3.2.5 Chemical Substitution

Chemical substitution, implemented by several Benchmarking Survey respondents, includes the use of acid salt substitutes for hydrochloric and sulfuric acid (68, 102). One respondent (42) replaced nitric acid with a citric acid/sulfuric acid bath.

3.2.6 Uses for Spent Baths

Spent acid baths can be used as a wastewater treatment reagent for neutralizing highly alkaline wastes (12, 59, 79). Spent sulfuric baths containing iron can be used with chromium wastewater as a reducing agent. However, this practice may result in higher sludge production rates as compared to the use of conventional reagents such as sodium bisulfite.

3.3 Anodizing

The most common electrolytes used for anodizing are:

- Sulfuric acid
- Sulfuric and oxalic acids (used with “hard anodizing” process)
- Chromic acid.

The use of chromic acid raises the most significant environmental issues. Reduced use of the chromic acid process is one of the most important changes in anodizing that has taken place over the past 20 years. This change has occurred primarily because of environmental concerns. In most cases, other processes such as sulfuric acid anodizing have taken its place.

One particular application where chromic acid anodizing remains popular is coating aircraft parts, especially those with recesses. Recesses can trap electrolyte, and entrapped sulfuric acid would cause corrosion and possible part failure. Chromic acid does not appreciably attack aluminum alloys. Also, the chromic acid process has a less deleterious effect on fatigue life than does sulfuric acid anodizing. During the past 10 years, the aircraft industry has used a new process with a sulfuric-boric acid electrolyte to further reduce the use of the chromic acid process.

P2 efforts associated with sulfuric acid anodizing have capitalized on opportunities related to rinsing, anode use, ***bath maintenance***, and energy use.

Table 3-3 summarizes the following discussion regarding pollution prevention strategies for anodizing.

3.3.1 Water Use Reduction

A good rinsing configuration for this process is a two-stage ***counterflow rinsing*** arrangement (53). As with all processes, efforts should be directed at reducing ***drag-out***, which has a direct bearing on rinse water use. Rinse water control

Table 3-3. Summary of Pollution Prevention Strategy for Anodizing

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-in and drag-out to the maximum extent possible, control rinse water use.	Basic: • Reduce drag-in to avoid diluting anodizing bath. • Reduce drag-out to decrease water use. • Install two-stage counterflow rinse tanks Advanced: • Install conductivity, pH, or timer controllers. • Spray rinsing using low water volume.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and using available maintenance technology. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize corrosion of busing, racks, fixtures, and parts; and retrieve parts or fixtures that fall into the bath). • Recycle WWT sludge off-site. • Use electrolysis to help maintain chromic acid solutions. Advanced: • Use advance technology to maintain the bath. Use acid sorption or diffusion dialysis for sulfuric acid baths and membrane electrolysis or ion exchange for chromic acid baths. • Use bath additive to sulfuric acid bath to permit higher operating temperature and lower electrical consumption.
Reduce Human Exposure *Strategy:* Minimize acid air emissions to workplace and community. Use less-toxic, substitute technologies, where applicable	Basic: • Employ adequate air speeds and ventilation rates to ensure removal of fumes or mists from inhalation zones. • Monitor inhalation zones to evaluate exposure and immediately correct any inadequacies. • Convert from chromic acid anodizing to a non-chromium process whenever possible. Advanced: • Use bath additive to reduce surface tension of chromic acid baths.

can be accomplished using pH controllers, or ***conductivity controls*** or a ***timer rinse control*** system.

Good rinsing practice includes drag-out reduction, use of counterflow rinses and good water use control (e.g., ***conductivity controls***) (104). One respondent (53) indicated it uses a foot-activated spray (mist) to rinse parts as they emerge from the process solution. Another respondent (92) indicated it uses “dead” rinses for solution recovery.

3.3.2 Anode Use

Sulfuric acid anodizing can be performed using either lead or aluminum cathodes. One survey respondent (53) indicated that it has substituted aluminum cathode rods for lead cathodes as a P2 measure.

3.3.3 Bath Maintenance

Bath maintenance is an important aspect of sulfuric acid anodizing. The anodizing process causes an increase in the concentration of dissolved aluminum. In conventional practice, the bath, or a portion of the bath, is replaced with fresh electrolyte. The spent solution is then typically neutralized and treated using a hydroxide precipitation process, a practice that creates sludge.

A fairly significant number of anodizers have implemented bath maintenance as an alternative to solution dumping. The most widely used technology for this purpose is ***acid sorption***, used by at least two of the survey respondents (58, 100). Another applicable technology is ***diffusion dialysis.***

One survey respondent (53) indicated that it bled spent anodizing solution into its wastewater treatment process, using the dissolved aluminum as a flocculent and improving the removal of heavy metals.

Another survey participant (135) operates a hard coat anodize tank with a maximum aluminum content of 3.75 g/ℓ. When that limit is exceeded, it uses the spent hard coat bath as replacement for a sulfuric acid anodize bath, a larger bath that requires a lower acid concentration and has a maximum allowable aluminum concentration of 18 g/ℓ. When the concentrated hard coat bath is used, water is also added to dilute the acid, and the aluminum concentration is proportionally diluted to about 3 g/ℓ. With periodic dumping of the sulfuric acid tank to a treatment system and replacing the sulfuric acid bath with the used hard coat solution, the aluminum sulfuric acid bath never exceeds the 18 g/ℓ limit. The hard coat solution contains additives that are not needed in the sulfuric acid process, but these additives have not caused any operational problems with the sulfuric acid anodizing process. This practice of reusing the hard anodize bath has been in effect for about 15 years.

3.3.4 Energy Use Reduction

One survey participant (34) reduced energy use with the sulfuric acid process by using a bath additive that permitted the bath temperature to be increased. This reduced the electrical requirements for cooling the anodizing solution. The same respondent indicated that use of a pulse rectifier reduced energy consumption for its hard anodizing process.

3.3.5 Special Practices for Chromic Acid

P2 efforts associated with the last few facilities that still use the chromium process have focused on reducing air emissions, good rinsing practices, and bath maintenance. The National Emissions Standards for Hazardous Air Pollutants (NESHAP) (40 CFR. §63.6) for chromium regulates air emissions from chromic acid anodizing. At least one respondent (53) uses a bath additive to lower surface tension, which, in turn, reduces air emissions. That same facility floats poly balls on the surface of the bath to reduce energy consumption.

Common bath contaminants associated with chromic acid anodizing include chloride, sulfate, aluminum, and trivalent chromium. Using deionized water for evaporative makeup and rinsing can minimize chloride and sulfate introduction. High current density ***electrolysis*** can be used to remove sulfate and chloride, and convert trivalent chromium to the needed hexavalent form. Precipitation using silver oxide also removes sulfate. Some chromic acid anodizers use ***porous pots*** to remove aluminum and convert trivalent chromium to hexavalent chromium. Advanced technologies such as ***membrane electrolysis*** and ***ion exchange*** can also be used to remove dissolved aluminum.

3.4 Cadmium Plating

The number of cadmium plating operations in the U.S. and worldwide has declined significantly during the past 20 years due to considerable environmental and health concerns associated with cadmium metal. In some parts of the world, such as Europe, cadmium-plated parts cannot be imported or sold. Most cadmium electroplating has been replaced by zinc electroplating. Other popular alternatives include vacuum deposition of aluminum and zinc, and tin alloy plating.

Nevertheless, cadmium provides several distinct advantages over zinc; therefore, its use continues for certain applications. Cadmium:

- Provides superior corrosion protection in marine environments
- Is less apt to cause hydrogen embrittlement
- Has a dense and adherent oxide film that does not form bulky corrosion products.

Seventeen survey respondents (12.8%) perform cadmium plating. Two (43, 73) indicated that they are in the process of discontinuing cadmium plating. In an effort to retain customers while eliminating cadmium, one job shop (43) offers to perform R&D for customers to find alternative coatings. Cadmium plating is currently 6.4% of this shop's total metal finishing sales ($9.5 million).

Table 3-4 summarizes the following discussion regarding pollution prevention strategies for cadmium plating.

3.4.1 Water Use Reduction

Rinsing following cadmium plating presents challenges to the metal finisher. Due to the relatively low temperature of the cadmium bath, there is limited opportunity for use of drag-out recovery rinsing (see ***drag-in/drag-out recovery rinsing***). However, some companies use drag-out recovery rinsing (73) or ***spray rinsing*** (43) to capture and return ***drag-out*** to the process tank. The company using spray rinsing is able to recover all drag-out by spraying over a dead rinse (43) and returning that solution. This company, which plates zinc die castings (rack and barrel), has experienced a buildup of zinc in its cadmium plating tank, which is attributed to spray rinsing of the barrels. The zinc contamination problem may force the company to make design changes.

The drag-in/***drag-out tank*** arrangement is applicable to cadmium plating (132). Generally, a good strategy is to focus on drag-out minimization and to implement ***counterflow rinsing*** and good water use control. Drag-out reduction can be achieved by:

- Increasing dwell time (65, 123)
- Rotating racked parts for better drainage (127)
- Redesigning barrels to reduce the volume of trapped solution (60)

Table 3-4. Summary of Pollution Prevention Strategy for Cadmium Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out, employ counterflow rinsing, and exercise good rinse water use control.	Basic: • Reduce drag-out (e.g., thoroughly drain parts over process tank, rotate barrels above tank, use insoluble anodes). • Operate the bath at the lowest practical cadmium concentration. • Install drip guards and return solution to process tank. • Install counterflow rinsing. Advanced: • Use conductivity-controlled rinsing. • Implement recovery rinsing using a drag-out tank and/or a spray rinse. • Install drag-in/drag-out rinsing arrangement.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and performing bath maintenance. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize introduction of metallic impurities; use deionized water for bath additions; and retrieve parts or fixtures that fall into the bath). • Mix insoluble and soluble anodes to avoid metal buildup in bath. • Use bath maintenance methods to remove impurities. • Recycle WWT sludge off-site. Advanced: • None identified.
Reduce Human Exposure *Strategy:* Eliminate cadmium electroplating.	Basic: • Convert cadmium electroplating processes to zinc electroplating. Advanced: • Substitute aluminum vapor deposition, zinc or tin alloy, or other coating for cadmium electroplating processes.

- Rotating barrels above the plating tank after they exit the solution (98, 114) (see ***draining/rinsing over the plating tank***)
- Training operators (61).

Operating the cadmium plating bath at the lowest practical metal level will also lower drag-out losses. Water use control can be accomplished using ***flow restrictors***, ***conductivity controls***, shut-off valves, and ***timer rinse controls***.

3.4.2 Bath Maintenance

Cadmium baths tend to increase in metal concentration over time due to the difference in anode and cathode plating efficiency. Some platers compensate for this increase by adding other bath constituents to maintain recommended ratios. This procedure results in significantly higher levels of cadmium in the drag-out.

An alternative method is to control the cadmium metal concentration in the bath using a combination of insoluble anodes (carburized steel balls) with soluble anodes. Other accepted ***bath maintenance*** methods include ***filtration*** and carbonate control (using chilling system).

3.4.3 Chemical Recovery

Various chemical recovery technologies have been used with cadmium electroplating. The most frequently used technologies are ***electrowinning*** and evaporative recovery (vacuum type). ***Ion exchange*** has also been used, but with less success than the other two recovery technologies (see footnote 1, page 3-1).

3.5 Copper Plating

Operating environmentally efficient copper electroplating processes begins with the selection of the plating bath. Twenty years ago, most copper plating was performed from cyanide baths. However, acid copper baths have become the predominant choice for meeting most metal finishers' needs.

Unfortunately, acid copper baths cannot be used to plate copper directly onto steel or zinc (both of which are commonly plated). In these cases, a copper cyanide strike (thin deposit) can be used, followed by an acid copper solution. This strategy greatly reduces the quantity of cyanide used. Alternatively, copper pyrophosphate strike solutions are employed by some shops to avoid the cyanide bath when plating steel substrates. In addition, proprietary alkaline, non-cyanide copper plating processes may allow the use of a single solution to replace the two-step copper strike-plate process. However, the use of such solutions is not widespread.

Table 3-5 summarizes the following discussion regarding pollution prevention strategies for copper plating.

3.5.1 Water Use Reduction

Minimizing ***drag-out***, using multiple rinse tanks, and controlling water use can achieve water use reduction. To reduce drag-out, efforts should focus on:

- Rack design
- Part orientation
- Dwell times.

To meet rinsing needs and lower water use, typically, a two-stage ***counterflow rinsing*** configuration will suffice following copper plating. Although ***drag-out tanks*** for recovery are typically not employed with copper plating, they can be used with baths operated above 100°F. One survey respondent (67) indicated it uses ***recovery rinsing*** on copper plating. On continuous production lines, where rinse water needs are relatively stable, flow can be controlled easily by periodically monitoring rinse water conductivity and manually adjusting flow using a valve. If workflow is sporadic, a ***conductivity control*** or ***timer rinse control*** should be considered. These devices help to match rinse water use and production flow.

Table 3-5. Summary of Pollution Prevention Strategy for Copper Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out, employ counterflow rinsing, and exercise good rinse water use control.	Basic: • Reduce drag-out. • Install counterflow rinsing. Advanced: • Use conductivity-controlled rinsing. • Employ recovery rinsing for baths with elevated temperature.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing buildup of zinc and metallic bath contamination. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize introduction of metallic impurities; use deionized water for bath additions; and retrieve parts or fixtures that fall into the bath). • Use common bath maintenance methods to remove impurities. • Recycle WWT sludge off-site. Advanced: • Use equipment for automatic additions of certain bath components.
Reduce Human Exposure *Strategy:* Use non-cyanide copper electroplating processes.	Basic: • Convert copper cyanide electroplating processes to non-cyanide processes wherever possible. Advanced: • Eliminate cyanide strike process whenever possible.

3.5.2 Bath Maintenance

Copper electroplating baths are rarely discarded. Common ***bath maintenance*** methods include ***filtration*** (removes suspended solids), carbon treatment (removes organic contaminants), low current density ***electrolysi***s (removes dissolved contaminants), and carbonate freezing or carbonate precipitation (removes excessive carbonate from cyanide baths).

Automated bath analyses and control systems can be used with copper electroplating. With acid copper plating, liquid chromatography monitoring of chloride concentrations is sometimes used. Analyses of organic additives (brighteners, ***wetting agents***) in copper baths usually require some method development(see footnote 2, page 3-1).

3.5.3 Chemical Recovery

Various chemical recovery technologies have been used with copper electroplating. The most frequently used technologies are ***ion exchange***, ***electrowinning*** 64), and evaporative recovery.

3.6 Decorative Chromium Plating

Although some of the same strategies used for hard chromium plating (see Section 3.8) are applied to decorative chromium plating, several key factors have caused companies to take some approaches specific to decorative chrome. These factors include:

- Lower plating bath temperature (<125°F)
- Higher average drag-out rates
- Widespread use of a substitute plating solution (trivalent chromium).

The advantages to using the trivalent solution include the following:

- Trivalent chromium baths reduce human exposure to toxic hexavalent chromium compounds.
- During operation, the trivalent bath does not mist like the hexavalent bath.
- Trivalent baths also have a significantly lower chromium concentration and lower viscosity, both of which reduce the quantity of chromium lost due to drag-out.

Some survey respondents (13, 43, 47, 67, 121, 130) have successfully implemented trivalent chromium plating.

Decorative chromium also presents some environmental challenges. For example, the lower bath temperature and higher drag-out rate make implementing closed-loop rinsing more difficult than with hard chromium plating.

Table 3-6 summarizes the following discussion regarding pollution prevention strategies for decorative chromium plating.

3.6.1 Water Use Reduction

A good formula for environmental success with decorative chromium plating includes drag-out minimization, direct recovery, and ***counterflow rinsing*** with good water use control. ***Drag-out*** can be minimized by orienting parts on racks such that they drain completely, slowly withdrawing parts from the process solution, suspending the parts over the process tank for drainage (see ***draining/rinsing over the plating tank***), and using a drag-out recovery rinse followed by a multiple-stage counterflow rinse.

Table 3-6. Summary of Pollution Prevention Strategy for Decorative Chromium Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out and, to the maximum extent possible, return residual drag-out to the process tank, and minimize rinse water use.	Basic: • Reduce drag-out (e.g., good racking, slow withdrawal from process solution, thoroughly drain parts over process tank, use wetting agent, and operate bath at lowest possible chromium concentration). • Install drip guards and return solution to process tank. • Perform initial rinsing (spray) over the process, if feasible. • Use drag-out rinse tank with return of solution to process tank, followed by counterflow rinse. Advanced: • Install drag-in/drag-out rinsing arrangement. • Install closed loop rinsing with multiple drag-out tanks (2–4) connected in a counterflow arrangement. • Where drag-out rate is high and surface evaporation is minimal, install auxiliary evaporation (e.g., atmospheric evaporator). • Recycle water from process tank heat exchangers.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and using available maintenance technology. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize corrosion of busing, racks, fixtures, and parts; use deionized water for rinsing; and retrieve parts or fixtures that fall into the bath). • Recycle WWT sludge off-site. Advanced: • Recycle air scrubber/mesh pad wash-down back to process tank. • Filter stripping and plating solution to remove suspended contaminants. • Use bath maintenance technology (e.g., ion exchange or membrane technology) to keep Cr^{+3} and metallic contaminants at low levels. This also reduces energy requirements for solution heating and plating.
Reduce Human Exposure *Strategy:* Minimize chromium air emissions to workplace and community. Use less-toxic, substitute chemistry.	Basic: • Employ adequate air speeds and ventilation rates to ensure removal of mists from inhalation zones. • Monitor inhalation zones to evaluate exposure and immediately correct any inadequacies. Advanced: • Employ mesh pad mist eliminators to remove and recover chromium from ventilated air. • Control surface tension of plating bath. • Use trivalent chromium plating chemistry.

Another approach to drag-out minimization is to operate the bath at a lower, but still acceptable, chromium concentration. A number of survey respondents (4, 38, 47, 94, 63, 67) have implemented most or all of these P2 elements.

Water use control is often achieved simply with ***flow restrictors*** due to the continuous nature of workloads. However, for decorative chromium lines that are not operated continuously, additional controls are needed, such as ***conductivity controls*** or ***timer rinse controls***. Due to the lower bath temperature and higher drag-out rates, most companies do not achieve ***closed-loop*** rinsing, although two exceptions were identified by the survey (4, 14). As a result, companies frequently install recovery equipment, the most successful of which is the ***atmospheric evaporator*** (see footnote 1 on page 3-1).

One company (14) that has closed-loop rinsing employs a drag-in tank and three rinses following plating that are organized in a counterflow arrangement. This company also has a separate "holding tank." Deionized water is fed to the last rinse and counterflows to the first rinse. The solution in the first rinse flows to a holding tank. The plating solution is circulated continuously to the holding tank. The holding tank provides flow equalization by balancing the incoming water flow rate and the evaporation rate in the plating tank. ***Bath maintenance*** (***porous pot***) is also performed in the holding tank, which saves plating tank space. The drag-in solution is circulated to the first rinse tank. A "bubble pump" (no moving parts) is used to circulate (3.5 gpm) the drag-in tank solution. This arrangement is referred to as a ***drag-in/drag-out recovery rinsing*** scheme. It contributes to closing the loop on rinsing. One other survey respondent (132) indicated that it uses drag-in/drag-out recovery rinsing.

Survey respondents listed additional P2 methods that relate to rinsing. These include using ***wetting agents*** to reduce viscosity (47, 91), and ***spray rinsing*** parts over the process tank (4, 47).

3.6.2 Bath Maintenance

Returning drag-out to the process tank may result in a buildup of contaminants in the plating bath. This buildup is especially a concern with zero wastewater operations. Contaminants, contributed from various sources, can lead to slower plating rates and poor deposits. The initial line of defense against contaminant buildup is prevention. Examples of good practices include:

- Thoroughly cleaning parts before plating
- Minimizing corrosion of busing, racks, fixtures and parts
- Using deionized water for rinsing
- Avoiding drag-in of sulfate and chlorides
- Avoiding exclusively plating inner diameters
- Retrieving parts or fixtures that fall into the bath.

To deal with contaminant buildup, which occurs even when prevention is employed, companies can install bath maintenance technologies. Methods used include filtering, porous pots, and more advanced technologies such as ***membrane electrolysis*** and ***ion exchange***.

3.6.3 Air Quality

Decorative hexavalent chromium plating causes the evolution of chromic acid mist. The quantity of misting is generally much less than with hard chromium plating. ***Fume suppressants*** can be used to lower the surface tension of the bath and thereby reduce the generation of fumes (67). One respondent (91) suggested that maintaining the surface tension below 45 dynes/cm greatly reduces the amount of mist being generated and reduces drag-out.

Well-designed and operated ventilation systems prevent the chromium fumes from entering the workplace. In turn, the ventilated air is processed by ***scrubbers*** and/or ***mist eliminators*** to prevent emissions of chromic acid to the atmosphere.

3.7 Electroless Nickel Plating

Compared with solutions used with electroplating processes, electroless nickel plating baths have a very limited life span. Because these baths are discarded regularly, electroless nickel plating generates a significant quantity of waste.

Table 3-7 summarizes the following discussion regarding pollution prevention strategies for electroless nickel plating.

3.7.1 Bath Maintenance

Operating environmentally efficient electroless nickel plating processes begins with efforts to maintain the bath in usable condition for an extended time. Minimizing outside contamination and maintaining the bath's constituents at proper concentrations can accomplish this. Also, new technology is available to regenerate baths and keep them operating for an extended time.

The overall electroless nickel deposition reaction can be generally written as $3NaH_2PO_2 + 3H_2O + NiSO_4 = 3NaH_2PO_3 + H_2SO_4 + 2H_2 + Ni_0$. Sodium hypophosphite ($NaH_2PO_2$) reduces nickel sulfate to metallic nickel, and is oxidized to sodium orthophosphite (NaH_2PO_3). As the deposition of nickel proceeds, the orthophosphite concentration increases. Nickel salts and other constituents are added to the bath to make up for the chemicals consumed by the plating process. However, the process cannot continue indefinitely because of the buildup of by-products. The quality of the nickel deposit diminishes over time and the nickel bath must be discarded after 10 to 12 turnovers. (One turnover is said to occur when the cumulative amount of nickel added is equivalent to the original quantity in the bath.)

The deterioration of the bath is caused mainly by an excessive buildup of orthophosphite. In recent years, ***electrodialysis*** has been used to reduce orthophosphite to hypophosphite without altering other bath constituents, thereby prolonging the

Table 3-7. Summary of Pollution Prevention Strategy for Electroless Nickel Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Reduce drag-out, employ counterflow rinsing, and exercise good rinse water use control.	Basic: • Reduce drag-out (e.g., good rack design, operator training, drain parts over process tank, and spray rinsing over tank). • Install drip guards and return solution to process tank. • Install counterflow rinsing. Advanced: • Install spray rinsing over the process tank. • Use conductivity-controlled rinsing.
Improve Material Utilization *Strategy:* Minimize solution disposal (increase turnovers) by reducing introduction of contaminants and controlling bath constituents. Recycle baths/nickel.	Basic: • Avoid bath contamination (clean parts thoroughly before plating and use deionized water for bath additions). • Employ adequate filtration. • Avoid overheating bath. • Cool bath when idle to reduce breakdown of constituents. • Strip tank walls to prevent excessive plate out. • Recycle baths (or plated-out nickel metal) off-site. Advanced: • Install electrolytic recovery of nickel from rinse water. • Use equipment for automatic analyses and additions of certain bath components. • Install electrodialysis equipment to prolong bath life.
Reduce Human Exposure *Strategy:* Avoid worker exposure to toxic chemicals and other hazards.	Basic: • Always enforce use of appropriate personal protection equipment. • Provide adequate ventilation. Advanced: • Change type of chemistry employed to avoid ammonium hydroxide.

life of the bath. The new process has not seen widespread use, primarily due to cost.

Companies must strive to keep the electroless nickel bath in good working condition to avoid premature disposal. Methods used by survey respondents include:

- Deionized water for bath makeup or replenishment (21, 55)
- Small and frequent additions of chemicals (147)
- High ***filtration*** rates (21, 53, 116)
- Automatic equipment for solution analysis and chemical additions (21, 136)
- Closely maintained, proper bath temperature (i.e., avoiding overheating) (124)
- Cooling the bath when not in use to reduce breakdown of constituents (124)
- Periodic stripping of the plating tank walls to prevent excessive plate-out (124).

3.7.2 Disposal of Spent Baths

When baths deteriorate and require disposal, companies may process them on-site to recover the nickel (plate out metal onto steel wool) (17, 21) or send the baths off-site for recycling. Some chemical suppliers offer bath recycling (136). Recycling avoids treating the spent electroless nickel bath, which is a difficult task due to the presence of complexing agents such as EDTA.

3.7.3 Water Use Reduction

Survey respondents employ common methods for ***drag-out*** reduction such as good rack design and good racking practices (21, 66, 136), operator training (21, 136), draining parts over the process tank (66) (see ***draining/rinsing over the plating tank***), and water use control methods such as ***flow restrictors*** (21, 44, 58). Rinsing following electroless nickel plating typically consists of two to three counterflow rinses. Some companies (4, 44) use ***recovery rinsing***, but there is concern that it may lead to faster deterioration of the bath. Also, some companies use ***spray rinsing*** over the bath (17, 21, 102, 104) (see draining/rinsing over the plating tank).

3.7.4 Air Quality

Electroless nickel processes should be ventilated to avoid emissions within the workplace. One survey respondent indicated it uses a ***scrubber*** to remove contaminants from the ventilated air stream (21). Two survey respondents (53, 104) switched from using a plating solution containing ammonia hydroxide for pH control to one with potassium carbonate to reduce employee exposure.

3.8 Hard Chromium Plating

The key to environmental success with hard chromium plating is direct recovery. The hard chromium bath is operated at an elevated temperature (130 – 140°F). This results in surface evaporation rates of 0.05 to 0.07 gal/hr/ft^2. A 48-in. x 96-in. process tank operated at 140°F will evaporate 2.24 gal/hr or about 54 gal over the course of 24 hours, which provides an opportunity to recover an equal volume of solution.

Table 3-8 summarizes the following discussion regarding pollution prevention strategies for hard chromium plating.

3.8.1 Drag-out Recovery

Companies can maximize use of this recovery opportunity by returning concentrated solution to the process tank. Solution includes drips from parts exiting the process tank, solution caught by splash guards or trays, ***scrubber*** water or mesh pad wash-down, and solution from rinsing. Because rinsing can generate a large volume of dilute chromium-bearing water, it is important that a well-engineered, multiple-tank configuration be employed that concentrates the ***drag-out*** into the smallest possible volume. In most cases, a three-stage ***counterflow rinsing*** arrangement will generate a sufficiently low flow that the

Table 3-8. Summary of Pollution Prevention Strategy for Hard Chromium Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out and, to the maximum extent possible, return residual drag-out to the process tank.	Basic: • Reduce drag-out (e.g., use masking that does not trap excess solution, thoroughly drain parts over process tank, use wetting agent and/or operate plating bath at high end of allowable temperature range, and operate bath at lowest possible chromium concentration). • Install drag-out racks over tanks or drip guards and return solution to process tank. • Perform initial rinsing (spray) over the process, if feasible. • Use drag-out rinse tank with return of solution to process tank, followed by counterflow rinse. Advanced: • Install drag-in/drag-out rinsing arrangement. • Install closed-loop rinsing with multiple drag-out tanks (2–4) connected in a counterflow arrangement. • Where drag-out rate is high and surface evaporation is minimal, install auxiliary evaporation (e.g., atmospheric evaporator). • Recycle water from process tank heat exchangers.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and using available maintenance technology. Recycle WWT sludge.	Basic: • Unrack parts over process tank to catch drips and rinse off masking in rinse tank prior to disposal. • Avoid bath contamination (clean parts thoroughly before plating; minimize corrosion of busing, racks, fixtures, and parts; use deionized water for rinsing, avoid drag-in of sulfate and chlorides; avoid exclusively plating inner diameters; and retrieve parts or fixtures that fall into the bath). • Recycle WWT sludge off-site. Advanced: • Recycle air scrubber/mesh pad wash-down back to process tank. • Filter stripping and plating solution to remove suspended contaminants. • Use bath maintenance technology (e.g., ion exchange or membrane technology) to keep Cr^{+3} and metallic contaminants at low levels. This also reduces energy requirements for solution heating and plating.
Reduce Human Exposure *Strategy:* Minimize chromium air emissions to workplace and community. Use less-toxic, substitute technologies, where applicable.	Basic: • Use mist suppressants or poly balls to reduce the generation of mists from the chromium plating process. • Employ adequate air speeds and ventilation rates to ensure removal of mists from inhalation zones. • Monitor inhalation zones to evaluate exposure and immediately correct any inadequacies. Advanced: • Employ mesh pad mist eliminators to remove and recover chromium from ventilated air. • Consider use of alternative coatings (e.g., electroless nickel, nickel alloys, spray coatings, or vacuum coatings).

entire volume of rinse water can be returned to the bath. In situations where there is insufficient surface evaporation to achieve zero wastewater discharge, an ***atmospheric evaporator*** can be installed to increase the overall evaporation rate.

Survey respondents listed additional P2 methods that relate to rinsing. These include use of ***drag-in/drag-out recovery rinsing*** (132), splash guards on all tanks (68), using ***wetting agents*** to reduce viscosity (132), suspending racks over the process tank to drain (66), ***spray rinsing*** parts over the process tank (66, 55, 123), and unracking over the process tank (17) (see ***draining/rinsing over the plating tank***).

3.8.2 Bath Maintenance

Returning drag-out to the process tank may result in a buildup of contaminants in the plating bath. This buildup is of particular concern with zero wastewater operations. Contaminants, contributed from various sources, can lead to slower plating rates and poor deposits. The initial line of defense against contaminant buildup is prevention. Examples of good practices include:

- Thoroughly cleaning parts before plating
- Minimizing corrosion of busing, racks, fixtures and parts
- Using deionized water for rinsing
- Avoiding drag-in of sulfate and chlorides
- Avoiding exclusively plating inner diameters
- Retrieving parts or fixtures that fall into the bath.

To deal with contaminant buildup, which occurs to a certain extent even when prevention is employed, companies can install ***bath maintenance*** technologies. Methods used include filtering (19), ***porous pots*** (66), and more advanced technologies such as ***membrane electrolysis*** and ***ion exchange***.

3.8.3 Air Quality

Hard chromium plating causes the evolution of chromic acid mist. Well-designed and operated ventilation systems prevent the chromium fumes from entering the workplace. In turn, scrubbers and/or ***mist eliminators*** prevent emissions of chromic acid to the atmosphere. One respondent indicated that it employs floating polypropylene balls and a ***fume suppressant*** to reduce the generation of mists. That same company also employs a mist eliminator (17). A different respondent (68) has “completely covered” its hard chromium tanks and is using a fume suppressant and mist eliminator. Mist eliminators can be designed to recover the chromic acid that enters the ventilated air stream.

3.9 Nickel Plating

Nickel plating pollution prevention practices include a wide range of activities and technologies relating to ***drag-out*** prevention and recovery, rinse water minimization, plating ***bath maintenance***, and in-process recovery.

Table 3-9 summarizes the following discussion regarding pollution prevention strategies for nickel plating.

3.9.1 Water Use Reduction

Rinsing following nickel electroplating should include drag-out recovery and counter flow rinsing (13, 34, 47, 59, 63, 126, 107, 121).

Some survey respondents (14, 59, 126) have achieved zero water discharge using three to four recovery tanks connected in a counterflow arrangement. ***Recovery rinsing*** will accelerate the buildup of impurities, which must be dealt with (see Section 3.9.4). Otherwise, bath disposal or recovery will be necessary (6).

When continuous workloads are encountered, water use control can be achieved simply with ***flow restrictors*** (47) and by closing water valves when plating lines are idle. However, for nickel lines that are operated intermittently, additional controls are needed, such as ***conductivity controls*** (121) or ***timer rinse controls***.

One company (14) that has ***closed-loop*** rinsing employs three rinses following nickel plating that are organized in a counterflow arrangement. This company also has a separate “holding tank.” Deionized water is fed to the last rinse and counterflows to the first rinse. The solution in the first rinse flows to a holding tank. The holding tank provides flow equalization for the deionized water flow rate and the evaporation rate in the plating tank. During the work week, the quantity of solution in the holding tank increases. Over the weekend, the idle nickel plating tank is kept at its normal operating temperature

Table 3-9. Summary of Pollution Prevention Strategy for Nickel Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out and, to the maximum extent possible, return residual drag-out to the process tank, and minimize rinse water use.	Basic: • Reduce drag-out (e.g., good racking, slow withdrawal from process solution, thoroughly drain parts over process tank, use wetting agent, and operate bath at lowest possible nickel concentration). • Install drip guards and return solution to process tank. • Use drag-out rinse tank with return of solution to process tank, followed by counterflow rinse. Advanced: • Install closed-loop rinsing with multiple drag-out tanks (2–4) connected in a counterflow arrangement. • Where drag-out rate is high and surface evaporation is minimal, install auxiliary evaporation (e.g., atmospheric evaporator).
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and using available maintenance technology. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize corrosion of busing, racks, fixtures, and parts; use deionized water for rinsing; and retrieve parts or fixtures that fall into the bath). • Use bath maintenance technology (e.g., filtration, carbon treatment, high pH) to keep metallic and organic contaminants at acceptable levels. • Recycle WWT sludge off-site. Advanced: • Install in-process recovery technology.
Reduce Human Exposure *Strategy:* Minimize nickel air emissions to workplace and community. Use less-toxic, substitute chemistry for stripping.	Basic: • Avoid emitting plating fumes into inhalation zones. • Monitor inhalation zones to evaluate exposure and immediately correct any inadequacies. Advanced: • Use less-hazardous stripping solutions (avoid cyanide and nitric acid)

so that evaporation continues. During this time, a significant percentage of the solution in the holding tank is transferred to the plating tank. The return flow is pumped through a carbon filter, thus providing solution maintenance.

3.9.2 Chemical Recovery

Another survey respondent (64) uses an ***ion exchange*** system for recovering nickel (64). This company's plating tank is followed by three rinses, connected in a counterflow configuration. A conductivity probe is present in the first rinse, nearest the plating tank (most concentrated rinse). When the conductivity reaches a set point, solution in the first rinse is transferred to the ion exchange holding tank (220 gal). This flow is balanced by the addition of deionized water to the last rinse. The solution in the ion exchange holding tank is pumped through dual filters and the ion exchange column, which contains a cation bed that retains the nickel. The ion exchange unit is regenerated with sulfuric acid, and nickel sulfate is eluted. A small volume of hydrochloric acid is added to the recovered solution to destroy organics. The resultant nickel sulfate is tested using a Hull cell and is subsequently used to replenish the plating bath. The water processed through the ion exchange unit is treated by a second ion exchange step to remove any residual nickel and is then discharged to sewer, without the need for conventional treatment. Regenerant from the second ion exchange unit is recycled off-site.

In-process recovery is often used with nickel electroplating. The most common technology employed is the ***atmospheric evaporator*** (34). This technology is typically used in conjunction with recovery rinsing. Other applicable technologies include ***vacuum evaporators***, ***ion exchange***, ***electrowinning***, ***reverse osmosis***, and ***electrodialysis***.

3.9.3 Additives

Anti-pitting agents are used to lessen pitting in nickel electroplating. The agent promotes the release of gas bubbles from the surface of the part. Anti-pitting agents also reduce surface tension of the solution, which, in turn, will help solution drain from the part, minimizing drag-out (see footnote 2 on page 3-1).

3.9.4 Bath Maintenance

Prevention of bath contamination and bath maintenance are key aspects of P2 for nickel electroplating operations. Below are some important considerations and alternatives.

During electroplating, the nickel anode dissolution efficiency is 100%. The cathode efficiency of nickel plating is typically 95–98%. When a moderate to high concentration of bath contaminants is present, the cathode efficiency can drop below 90%. This situation may cause the nickel content of a bath to increase over time, especially when recovery rinsing is used. To prevent the wasteful buildup of nickel metal, it is important to eliminate all sources of contaminants in the nickel plating bath.[2] Even when contaminants are kept to a minimum, closed-loop nickel systems will build up in nickel concentration (147). The holding tank concept used by one respondent (described in Section 3.9.1) may help in dealing with this problem (14).

Copper anode buss bars can be a source of copper contamination, which is quite detrimental in nickel plating. A number of options are available that reduce the introduction of copper contamination in nickel plating:

- Wrap buss bars with a plating grade of non-adhesive vinyl tape, except for contact areas
- Plate copper bars with nickel
- Install PVC drain boards over the anode bars (see footnote 2 on page 3-1).

Parts fallen into the tank are a significant source of contamination and should be removed quickly. An inexpensive tank magnet can be used for retrieving ferrous parts. A siphon hose or make-shift shovel can be used to remove non-ferrous materials (147).

During electroplating, the organic additives of nickel baths produce decomposition products that, if allowed to accumulate, can result in unacceptable plating. To help reduce the occurrence of these problems, finishers filter the solution continuously through activated carbon. One respondent (43) indicated that it uses a cartridge-type carbon filter, which is believed to create less waste than other types of filters. If excessive carbon treatment is needed on a regular basis, the plating procedures should be reviewed to identify sources of organic contamination (e.g., drag-in, poor cleaning) and these should be eliminated.[2]

Electrolytic treatment (dummying) can be effectively used for removal of copper, zinc, iron, and excesses of certain organic brightening agents. In this treatment, a corrugated cathode is used, and the bath is electrolyzed at 2–4 ampere per square foot (asf) (see footnote 2 on page 3-1). One survey respondent (121) indicated that it has implemented continuous electrolytic treatment by adding a holding tank with a separate rectifier. Solution from the bath is transferred continuously to the holding tank and returned to the bath. The circulation loop includes carbon ***filtration***.

Metal precipitation or "high pH" treatment can be used for removal of aluminum, iron, and silicates. Removal is accomplished by transferring the solution to a batch treatment tank, raising the temperature (145–150°F), and adding a slurry of plating-grade nickel carbonate (raises pH to 5.2). Hydrogen peroxide can be added to help oxidize the iron. The solution is filtered and returned to the plating tank (see footnote 2 on page 3-1). One survey respondent pointed out that high pH treatment results in solution loss, sludge creation, and holding tank cleaning. Instead of performing this type of bath maintenance, this company periodically decants a portion of the bath and reuses it on-site or recycles it off-site (6).

3.9.5 Additional Methods

Survey respondents listed additional P2 methods for nickel electroplating. These include:

- Converting from a nitric acid strip to a less hazardous and regenerable sulfuric acid/ peroxide process (43)
- Replacing cyanide stripper with non-cyanide stripper (59)
- Employing equipment rotators to improve drainage of drag-out (127)
- Using a closed-loop chiller system to control bath temperature (47).

3.9.6 Air Quality

Nickel electroplating releases only very small quantities of nickel into the air. Well-designed electroplating processes prevent plating fumes from entering the workplace.

3.10 Tin and Tin–Lead Plating

There are various pollution prevention opportunities for tin and tin–lead plating operations. The most common focus on alternative processes for tin–lead, reducing water use, plating solution control and maintenance, and recovery.

Table 3-10 summarizes the following discussion regarding pollution prevention strategies for tin and tin–lead plating.

3.10.1 Alternative Processes

Tin–lead is commonly used by the printed wiring board (PWB) industry and for other electronics applications. In PWB manufacturing, tin is essentially just as effective as tin–lead as an etch-resist and can replace tin–lead plating when solder-mask-over-bare-copper (SMOBC) is employed. Tin-only baths can be used as a substitute in many other cases; however, not for all current tin–lead applications. Emerging substitute technologies include tin–bismuth alloys, conductive adhesives, and nickel–gold or nickel–palladium electroplating.

Table 3-10. Summary of Pollution Prevention Strategy for Tin and Tin–Lead Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out, employ counterflow rinsing, and exercise good rinse water use control.	Basic: • Reduce drag-out. • Operate the bath at the lowest practical metal concentration. • Install drip guards and return solution to process tank. • Install counterflow rinsing. Advanced: • Use conductivity-controlled rinsing. • Install drag-out rinsing arrangement with baths above 100°F.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing bath contamination and performing bath maintenance. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize introduction of metallic impurities by using high-purity anodes; use deionized water for bath additions; and retrieve parts or fixtures that fall into the bath). • Use bath maintenance methods to remove impurities. • Recycle WWT sludge off-site. Advanced: • None identified.
Reduce Human Exposure *Strategy:* Eliminate lead from electroplating processes.	Basic: • Convert tin–lead processes to tin electroplating. Advanced: • Substitute tin–bismuth alloys, conductive adhesives, and nickel–gold or nickel–palladium for tin–lead electroplating processes.

3.10.2 Water Use Reduction

Metal finishers can achieve water use reduction in tin and tin–lead plating by minimizing ***drag-out***, using multiple rinse tanks, and controlling water use. To reduce drag-out, efforts should focus on rack design, part orientation, and dwell times. On continuous processes such as reel-to-reel plating for electronics, an air knife can be used to further reduce drag-out losses.

To reduce water use while still meeting rinsing needs following tin or tin–lead plating, a two-stage ***counterflow rinsing*** configuration will typically suffice. One survey respondent (126) indicated that it uses three-stage rinsing after tin plating. A ***drag-out tank*** for recovery can be used with baths operated above 100°F (e.g., potassium stannate or sodium stannate).

On continuous production lines, where rinse water needs are relatively stable, flow can be controlled easily by periodically monitoring rinse water conductivity and manually adjusting flow using a valve. If workflow is sporadic, a ***conductivity control*** or ***timer rinse control*** should be considered. These devices help to match rinse water use and production flow.

3.10.3 Bath Maintenance

Bath maintenance can reduce the incidence of discarding process solutions. The primary source of tin and tin–lead bath contamination is metal impurities from anodes. These contaminants can be partially avoided by purchasing high-quality/low-impurity anodes.

Dissolved metal impurities can be removed using low current density ***electrolysis*** (dummying). Stannic ion is an unavoidable contaminant that must be maintained at relatively low levels by performing continuous ***filtration*** and chemical treatment (102). Fluoborate baths are particularly subject to buildups of sludge. Therefore, continuous in-tank or external filtration during operation is recommended with these solutions.

Organic bath additives are decomposed during plating and will concentrate in the bath. A carbon treatment can be performed on tin–acid and tin–lead baths to eliminate all organics. Fresh organic additive is then reintroduced.

3.10.4 Chemical Recovery

Various chemical recovery technologies have been used with tin and tin–lead electroplating. The most frequently used technologies are ***ion exchange***, ***electrowinning*** and evaporative recovery.

3.10.5 Disposal of Spent Baths and Sludge

Tin and tin–lead sludges do not have significant economic value and are by themselves usually not recycled off-site. However, one survey respondent (69) indicated that it treats tin-bearing rinse waters and spent baths, and sends the resultant hydroxide sludge to a reclamation site .

3.11 Zinc Plating

Operating environmentally efficient zinc electroplating processes begins with the selection of the plating bath. Twenty years ago, most zinc plating was carried out with cyanide baths. Today, low-cyanide and non-cyanide plating solutions are available that meet most of the metal finishers' needs.

Many of the survey respondents (21, 23, 43, 52, 53, 59, 60, 65, 73, 79, 98) identified conversion from cyanide to non-cyanide as a major P2 improvement. Several of the respondents indicated that complete conversion to non-cyanide was not possible due to special work requirements. In such cases, companies have converted one or more tanks to non-cyanide and maintain a single zinc cyanide tank (43, 60) or have switched to a low-cyanide chemistry (53).

Zinc cyanide plating baths are significantly less affected by poor cleaning than alkaline non-cyanide baths. One respondent (60) noted that operating a zinc cyanide bath with floating oil is possible. Alkaline non-cyanide zinc plating requires extensive cleaning, similar to that needed for nickel plating directly onto steel (60).

Table 3-11 summarizes the following discussion regarding pollution prevention strategies for zinc plating.

3.11.1 Bath Maintenance

Even with non-cyanide baths, solution chemistry control must be exercised to minimize pollution generation. Several survey respondents (8, 37, 60, 81, 73, 93, 98) indicated that zinc plating bath control was an integral part of their P2 approach. Several survey respondents (8, 93, 98) indicated that the use of automatic chemical bath additions improves control. One survey respondent (37) controls the use of brightener by storing the chemical in totes, which platers cannot access without permission. This restriction has reduced brightener usage by 30% (37).

Important aspects of solution control include controlling metal buildup, making proper additions of bath components, and contamination control. Metal buildup can occur when zinc anodes dissolve during idle times. This situation can be avoided by removing the anodes from the solution when it is not in use (21, 53). This practice is more effective for alkaline baths than for zinc chloride baths.

Zinc metal concentration can also be controlled in cyanide and alkaline non-cyanide plating solutions using inert anodes (i.e., steel or carbon) (21, 59). Using deionized water for evaporative makeup, retrieving fallen parts or racks, ***filtration*** (21), and removing metallic impurities can accomplish contamination control. One respondent (57) uses permanent media filters rather than disposable filters to reduce the quantity of waste being discarded. ***Electrolysis*** is used to remove lead and cadmium. Various chemical treatments followed by filtration are also used to remove metallic impurities, including:

Table 3-11. Summary of Pollution Prevention Strategy for Zinc Plating

Objectives and Strategy	Potential Practices
Reduce Drag-Out and Water Use *Strategy:* Minimize drag-out, employ counterflow rinsing, and exercise good rinse water use control.	Basic: • Reduce drag-out (e.g., thoroughly drain parts over process tank, rotate barrels above tank, use wetting agent). • Operate the bath at the lowest practical zinc concentration. • Install drip guards and return solution to process tank. • Install counterflow rinsing. Advanced: • Use conductivity-controlled rinsing. • Install drag-in/drag-out rinsing arrangement.
Improve Material Utilization *Strategy:* Avoid solution disposal by minimizing buildup of zinc and metallic bath contamination. Recycle WWT sludge.	Basic: • Avoid bath contamination (clean parts thoroughly before plating; minimize introduction of metallic impurities; use deionized water for bath additions; and retrieve parts or fixtures that fall into the bath). • Recycle WWT sludge off-site. • Remove anodes from tank when not in use. Advanced: • Use inert anodes. • Use equipment for automatic additions of certain bath components. • Use bath maintenance methods to remove impurities.
Reduce Human Exposure *Strategy:* Use non-cyanide zinc plating processes.	Basic: • Convert zinc cyanide processes to non-cyanide processes wherever possible. Advanced: • Mechanical plating can be used as an alternative coating for some applications.

- Sulfide reagents (lead, cadmium removal)
- Sodium hydrosulfite (chromate removal)
- Zinc dust (cadmium and lead removal)
- Hydrogen peroxide (iron removal).

Activated carbon treatment is employed to remove organic impurities (cleaner components, plasticizers, and decomposition of additives).

One survey respondent (133) completely removes plating solution from its zinc plating tank when it is not in a production mode. This company indicated that this practice prevents buildup of organics on the anode baskets, extends the service life of anode baskets, prevents zinc metal buildup in the plating bath, and is a safeguard against tank failure.

3.11.2 Water Use Reduction

Rinsing following zinc plating presents challenges to the metal finisher. Due to the relatively low temperature of the zinc bath, there is limited opportunity for use of ***drag-out recovery rinsing*** (see ***drag-in/drag-out recovery rinsing***). However, some proprietary zinc chloride baths can be operated as high as 130°F, which is sufficiently high to make ***recovery rinsing*** feasible and effective. One respondent (98) uses an ***atmospheric evaporator*** to increase evaporation and recover plating solution. Although several survey respondents (65, 107, 631) indicated they employ recovery rinsing, most rely more on several other aspects of rinsing: ***drag-out*** minimization, ***counterflow rinsing***, and water use control.

Survey respondents have implemented drag-out reduction by:

- Increasing dwell time (21, 65, 73, 123)
- Rotating racked parts for better drainage (21, 127)
- Redesigning barrels to reduce the volume of trapped solution (60)
- Rotating barrels above the plating tank after they exit the solution (37, 60, 73, 98, 114) (see ***draining/rinsing over the plating tank***)
- Training operators (61).

Operating the zinc plating bath at the lowest practical metal level or using excess ***wetting agent*** will also decrease drag-out losses.

Numerous respondents cited water use control as a key aspect of pollution prevention on the zinc plating line. The equipment employed includes ***flow restrictors***, ***conductivity controls***, shut-off valves, and ***timer rinse controls***.

Although the traditional drag-out recovery rinse is not used by many of the survey respondents, at least two companies (114, 132) employ drag-in/drag-out recovery rinsing tanks to recover a portion of the drag-out.

3.11.3 Chemical Recovery

Various chemical recovery technologies have been used with zinc plating, although there are fewer total applications than with most other plating metals. The most frequently used technologies are evaporative recovery (98) and ***electrowinning***. ***Ion exchange*** has also been used, but with less success than the other two recovery technologies (see footnote 1 on page 3-1).

3.12 Other Processes

This section contains survey respondent comments* related to processes other than those specifically covered in previous sections. Readers may find some of these comments useful when evaluating their own practices and identifying new opportunities for pollution prevention. **However, readers should fully investigate and evaluate any options before implementing them**.

* Comments are essentially unedited except for spelling and other minor corrections to improve readability. Square brackets denote paraphrasing of respondent comments.

3.12.1 Phosphating

The following comments are pollution prevention methods survey respondents used to address phosphating.

- Automatic additions to phosphate baths—resulting in less human exposure (12).
- Changed to a chemistry that generates only one quarter of the sludge previously produced. Iron control system used on zinc-phosphate bath (12, 79).
- Installed motor-controlled hoists to reduce drag-out. Use counter flow rinsing. Conducted operator training. Installed bulk storage system and eliminated use of waste drums (36).
- Filter phosphate solution so we don't have to decant periodically (52). [One respondent indicated that this is not a very effective practice (79).]
- Converted existing rinse tanks to counterflow (52, 79).
- Use water restrictors. Increased dwell time. Installed drip pans. Use vacuum evaporator for recovery. Installed oil skimmer and microfilter on cleaner. Reduced concentration of chromium in sealers (magnesium phosphate) and use non-chromium sealers (zinc phosphate) (65).
- We have tried non-chromium sealers and will move into one shortly (133).
- Increased analysis of phosphate solution (73).
- Added acid filter. Increased analysis and bath maintenance (81).
- Use counterflow rinses. Use acid wetters (114).
- Use manual titration for prep and phosphating baths. Substituted water-soluble oil whenever customer requirements permit. Implemented operator training to minimize drag-out and water use and to extend bath life (136).
- Use counterflow rinsing (47).
- Installed counterflow rinses to reduce rinse water use, installed ***flow meters*** at all rinse tanks to reduce water use, installed oil separator on the cleaner system. Installed heat exchangers to heat zinc phosphating bath in place of live steam, saving zinc phosphate bath from displacement overflow. (79).

3.12.2 Passivation

The following comments are pollution prevention methods survey respondents used to address passivation.

- Pilot testing of an acid sorption unit will take place in early 2000 (12).
- Extended dwell time over process tank (21, 43, 53).
- Use deionized water for bath makeup (21, 53). Deionized water used throughout passivation line (43).
- Maintain racking orientation to achieve best drainage; allow sufficient drainage over process tanks (21, 66).
- Replaced nitric acid process with a proprietary citric-acid-based process. The new process is less toxic and dangerous, however it is more expensive to operate (52). [Another survey respondent is testing a citric acid process (43).]
- Installed oil skip process to reduce the oil flowing into the system, thereby reducing chemical usage (81).
- Changed acids and reduced the quantity of acid on site (89).

3.12.3 Black Oxide

The following comments are pollution prevention methods survey respondents used to address black oxide.

- Use dead rinses. Reduced acid concentration in pickle. Use flow restrictors (58).
- Use deionized water for rinsing and replenishment (55).
- Use counterflow rinsing (47).
- More efficient burners purchased (natural gas reduction) (34).
- Flow restrictors on water rinses. Plumbed existing rinse tanks to counterflow (52).
- Use oil recovery drip trays and recover oil from spin dryers (59).
- Water restrictors, dwell time, drip pans, caustic cleaner skimming and microfiltration, elimination of solvent-based cleaners, lower-VOC water-based oils, cold evaporation of water from waste production oils (a 65% reduction) (65).
- Automatic additions to the bath resulting in less human exposure. Better method for disposing of the sludge generated in the bath through waste treatment (12).
- New line installed—less hydroxide loss and better process control (115).
- Basic P2 methods. Equipment rotators for better drainage, cleaner recycling (127).

3.12.4 Electropolish

The following comments are pollution prevention methods survey respondents used to address electropolishing.

- Save rinse; closed-looped rinse system with evaporator used to maintain temperature of process tanks (4).
- Found end users for used electropolishing solution. Closed manufacturing loop to purify acidic rinse water. Sludge from clarifier is Class V non-hazardous (9).
- Rinse water is reused for different rinses up the line (14).
- Cover tanks when not in use to prevent adsorption of moisture from the air (147).

3.12.5 Painting

The following comments are pollution prevention methods survey respondents used to address painting.

- Partnering for a grant with the New York State Energy Research and Development Authority (NYSERDA) for elimination of VOCs from painting.
- Replaced 80% of solvent and water-based painting with powder coating processes (121).
- Have used powder coating since 1992 (57).

3.12.6 Polishing and Buffing

The following comment is a pollution prevention methods one survey respondent used to address polishing and buffing.

- Use trizact belts that last three times longer than previous belt (4, 121).

3.13 Additional Comments

This section contains survey respondent comments* that are not directed toward specific processes. Readers may find some of these comments useful when evaluating their own practices and identifying new opportunities for pollution prevention. **However, readers should fully investigate and evaluate any options before implementing them.**

* Comments are essentially unedited except for spelling and other minor corrections to improve readability. Square brackets denote paraphrasing of respondent comments.

3.13.1 General

The following comments are general pollution prevention methods used by survey respondents.

- The following waste minimization program has been implemented.
  1. Began recycling paper, cardboard and plastics, which otherwise went to general trash in late 1998. We reduced trash volume by 50% and saved approximately $500 in waste pickup fees.
  2. We segregate wastestreams to optimize wastewater treatment and waste disposal.
  3. EN, NDT, and phosphate department began use of a microbial cleaner. We now use one large tank and one small cleaning station to reduce soaps/solvent use (136).
- Monthly sharing bonus includes chemical use reduction bonus (37).
- Facility-wide use of rinse flow restrictors, counterflow rinses and drip covers (21, 43).
- Lab statistical process control (SPC) implemented to minimize chemical adds and bath efficiency (43).
- Implemented SPC to minimize chemical adds and bath efficiency, instituted reuse system for water treated by ion exchange (58).*
- Purchased AA [atomic absorption spectroscopy] for metal analyses (21, 43).
- Installed an automated control for pH adjustment, temperature control and brightener adds (43).
- Implemented water reuse of non-contact cooling water (21, 43).
- Upgraded electrical service to improve power factor rating (43).
- Added automated pH control for rinse waters to maximize ion exchange resin efficiency (43).
- Installed an ion exchange deionized recovery system for use on continuous rinse waters in an effort to reuse 80 to 85% of the rinse waters in one type of electroplating operation. If this is successful, we will incorporate a system for the general plating side of the plant (rack and barrel operations) (69).
- Built a new plant in 1998 with all elements of material handling, equipment design, chemical and energy conservation we could incorporate (93).
- We discontinued the use of cadmium and cyanide and reduced the use of all other hazardous constituents to the extent possible during the last three years. Also, well water, which has undergone remediation, is used for rinsing in process when possible (115).
- We apply evaporative-recycle techniques. We train and monitor personnel extensively. The end approach is a total package of train, educate, test, monitor, evaluate, modify—all directed to reducing emissions, NPO, and rejects. Source reduction is a goal with closed-loop as an end point (127).
- All of the following improvements were implemented for pollution prevention purposes.
  1. Extra hoists were installed to create longer dwell times.
  2. Drip guards installed on all tanks.
  3. Contaminant curbing installed.
  4. Daily log sheets are kept for production, chemical use, preventative maintenance, and workflow charts.
  5. Posted maintenance-free tank signs in both Spanish and English on all tanks.

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* Company uses ion exchange system and recycles processed water for rinsing in non-critical situations. Cost of regenerating ion exchange resin is $74,157 per year.

6. Purchased state-of-the-art plating barrels, which improved drainage and rinsing. These also have a special door to minimize operator error.
7. Installed counterflow rinse tanks.
8. Flow restrictors installed to control rinse flow.
9. Recovery rinse tanks installed.
10. All employees have specific duties and restrictions.

- We detailed each plating line with flow charts referring to procedures and documents for proper setting of water flows to counterflow rinses. Solution maintenance plans put into practice with procedures for makeup of new baths, and complete records of all additions and tests (68).

3.13.2 Energy

The following comments are pollution prevention methods survey respondents used to address energy.

- We had an energy audit performed by Bradley University and implemented most of their suggestions. (12)
- More efficient burners purchased (natural gas reduction) (34).
- Exploring cogeneration (62).
- Substitution of low energy lighting in selected areas (65).
- Installed pulse start metal halide lighting with lower wattage. Received utility rebate and financing (43).
- Replacing boilers, air conditioning units, and heaters with energy-efficient models; and tracking energy conservation/reductions (69).
- Use cogeneration for energy conservation/ reductions. Use natural gas to operate cogeneration unit. The system generates electricity and hot water. The hot water is used to heat all process tanks (121).
- [One survey participant reduced energy use with the sulfuric acid process by using a bath additive that permitted the bath temperature to be increased. This reduced the electrical requirements for anodizing. This same respondent indicated that use of a pulse rectifier reduced energy consumption for their hard anodizing process (34).]

3.13.3 Treatment/Disposal/Off-site Recycling

The following comments are pollution prevention methods survey respondents used to address treatment, disposal, and off-site recycling.

- We currently reuse 40% of the water after waste treatment for washdown and in noncritical rinses. Spent acids are used to help adjust pH in waste treatment (12).
- Combined many ideas to make it work: batch treatment, deionization units, high pressure RO [reverse osmosis], steam (97 [%] efficiency) evaporation, rinse tank batch dump, reuse all water, reduced water usage by 95% (13).
- An electrocoagulation system treats the wastewater with electricity instead of chemicals. This allows us to reduce our chemical costs by 22% and reduces waste treatments chemical costs by 84% (14).
- Planning to implement an electrocoagulation system (121).
- Filter-pressed sludge dried to 50% of volume (creating a non-hazardous material) before bulk landfill transfer (eliminating drums). Exchanging a 400-hp boiler for a 250-hp unit. Evaporation of oils creating a concentrated incinerator fuel feedstock. Substitution of sodium bisulfate and sodium hydroxide with hydroxyl ammonium sulfate (non-fuming) used for hexavalent

chromium reduction. Wood walkways replaced with fiberglass grating.

- Removed all old unused tanks. Removed waste treatment building and converted sludge storage building to non-hazardous dry storage. Removed 2,500,000-gallon waste treatment lagoons. Added an REM/CEA person to staff (89).
- [One survey respondent (147) indicated that it uses spent cleaners to neutralize acid waste streams in an effort to save on treatment chemicals.]

Appendix 3A: Glossary

Acid Sorption — Acid sorption (or retardation) is a separation process in which an acid is separated from its salts by using a column containing a strongly basic anion exchange resin.

The acid sorption process is most often applied to the maintenance of sulfuric acid anodizing baths and sulfuric acid and hydrochloric acid pickling baths. When these solutions are contaminated with dissolved metal, the free acid concentration decreases and the anodizing or pickling efficiency drops. Additions of fresh acid are possible up to a point, but eventually, the bath must be either purified or dumped.

During the sorption step, the acid and metal salt mixture is fed up through the resin bed. Acid is sorbed into the resin while the remaining dissolved metal salts are rejected as mildly acidic solution leaving from the top of the bed.

During the desorption step, water flows down through the resin bed. Acid is desorbed from the resin and displaced from the bottom of the bed.

Acid sorption does not recover all of the acid in a treated bath. Rather, it recovers only a percentage (typically 80–90%) of the “unused” or free acid (i.e., that acid which is not chemically bonded to the dissolved metal). Typically, 40–70% of the total acid is free acid. Therefore, if a shop’s current method of operation involves dumping and treating spent acid baths and replacing the bath with fresh solution, then acid sorption can be expected to reduce the shop’s total acid usage by approximately 30–65%.

Atmospheric Evaporator — An atmospheric evaporator is a device that evaporates water to the atmosphere.

Atmospheric evaporators are the most widely used method of chemical recovery in the plating industry. Some shops also use them to concentrate liquid plating wastes prior to hauling them off-site for treatment/disposal, thereby reducing transportation costs and, in some cases, treatment/disposal costs.

The commercial atmospheric evaporator used for recovery in the plating shop consists of a pump to move the solution, a blower to move the air, a heat source, an evaporation chamber in which the solution and air can be mixed, and a ***mist eliminator**** to remove any entrained liquid from the exit air stream. The evaporation chamber is usually filled with packing material or finned panels to increase the air-to-water interface.

In operation, the temperature of the solution being evaporated is elevated and the heated solution is introduced into the evaporation compartment. Air from the plating room is then blown through the compartment where it accepts the water vapor, and is then vented out of the chamber.

Commercial units are advertised to have evaporation rates of 10 to 90 gal/hr, depending on the size of the unit and operating conditions (e.g., solution temperature). Often, actual evaporation rates are considerably less because the atmospheric conditions within most plating shops do not match the ideal conditions under which the manufacturers rate their systems.

Bath Maintenance — Chemical solution (bath) maintenance includes a range of pollution prevention practices and technologies that preserve or restore the operating integrity of metal finishing process solutions, thereby extending their useful lives.

* Terms in bold italics denote a cross reference to other terms listed in this glossary.

Some forms of solution maintenance, such as ***filtration***, have been utilized nearly as long as metal finishing itself. However, due to rising costs for chemicals, energy, and treatment/disposal, and to increasingly more stringent environmental requirements, solution maintenance has become a greater priority to plating shops. The methods and technologies these shops employ have also increased in sophistication. Today, firms are willing to expend significant amounts of capital and operating funds for equipment and methods that primarily reduce the disposal frequency of their baths. In addition to extending bath lives, solution maintenance often improves the average operating efficiency and effectiveness of a process solution and, thus, has a positive impact on production rates and finish quality.

Closed-Loop — Closed-loop processing and zero discharge are terms often used by platers, vendors, consultants, and regulators. Various definitions are used for these terms, most of which recognize that 100% recovery/reuse of all materials (process chemicals, other chemicals, water, sludge, etc.) is not practical, economically feasible, nor efficient from an energy standpoint.

More realistically, all metal finishing shops as well as individual metal finishing processes generate some form of residuals. The residuals are typically in one or more of four common forms: wastewater, spent process solutions, sludge, or air emissions.

Some recovery/reuse can be implemented, but with every technology scheme or configuration, some residuals are generated. Often there is a trade-off between the quantity and characteristics of two or more of the four common residuals.

As a simple example, closed-loop rinsing after chromium plating will result in a buildup of contaminants in the bath. The rinse water discharge can be eliminated, but the bath will have to be either discarded or "purified." If the bath is purified, the purification process (e.g., ***porous pot***, ***membrane electrolysis***, or ***ion exchange***) will result in a residual that must be properly discarded.

Conductivity Controls — Conductivity control units consist of three components:

1. A probe or sensor located in the rinse tank that senses the conductivity of the rinse water
2. A transformer box that houses the solid-state circuitry that controls the system
3. A solenoid valve that opens and closes in response to signals from the circuitry.

In use, when ***drag-out*** is introduced to the rinse tank, the probe senses a rise in conductivity above a setpoint that is picked up by the circuitry, and the solenoid water valve is opened. The valve remains open until the probe senses a drop in conductivity below a setpoint. The setpoints are operator-adjustable to permit use over a range of desired water qualities.

Counterflow Rinsing — Electroplaters have long reduced water use by employing several rinse tanks connected in series. Fresh water flows into the rinse tank located farthest from the process tank and, in turn, overflows to the rinse tanks closer to the process tank. This technique is termed counterflow (or countercurrent) rinsing because the workpiece and the rinse water move in opposite directions.

Over time, the first rinse becomes contaminated with ***drag-out*** and reaches a stable concentration that is lower than the process solution. The second rinse stabilizes at an even lower concentration that enables less rinse water to be used than if only one rinse tank were in place. The more counterflow rinse tanks (three-stage, four-stage, etc.), the lower the rinse rate needed for adequate removal of the process solution.

Diffusion Dialysis — Diffusion dialysis is an ***ion exchange*** membrane technology that competes with ***acid sorption*** as a purification/recovery method for acids that have become contaminated with metals (e.g., pickling, anodizing, stripping, etching, and passivation baths).

The diffusion dialysis process separates acid from its metal contaminants via an acid concentration gradient between two solution compartments (contaminated acid and deionized water) that are divided by an anion exchange membrane. Acid is diffused across the membrane into the deionized water while metals are blocked due to their charge and the selectivity of the membrane.

Diffusion dialysis does not recover all of the acid in a treated bath. Rather, it recovers only a percentage (typically 80–90%) of the "unused" or free acid (i.e., that acid which is not chemically bonded to the dissolved metal). Typically, 40–70% of the total acid is free acid. Therefore, if a shop's current method of operation involves dumping and treating spent acid baths and replacing the bath with fresh solution, then diffusion dialysis can be expected to reduce the shop's total acid usage by approximately 30–65%.

Drag-In/Drag-Out Recovery Rinsing — This rinsing process (also referred to as double-dipping) involves rinsing in the same solution before and after plating. This can be achieved by using a single rinse tank or two hydraulically connected rinse tanks, usually located on opposite sides of the process tank. In the latter case, which is most applicable to automatic plating machines, the rinse water is recirculated between the two rinse tanks using a transfer pump to maintain equal concentrations of chemicals in the tanks.

The advantage of a drag-in/drag-out arrangement is that plating chemicals rather than pure rinse water are transferred into the process tank by incoming racks or barrels. This increases the recovery efficiency of the recovery rinse.

Drag-Out — Drag-out is the chemical solution film that clings to and remains on parts, racks barrels, etc. when they exit a tank.

For the typical electroplating job shop, the drag-out of process solutions and the subsequent contamination of rinse waters are its major pollution control problems. The quantity of drag-out generated depends on several factors, including solution temperature and viscosity, surface tension, rack/barrel design, position of parts, withdrawal rate, and dwell time (dripping) above the tank.

Various techniques can be applied to minimize the formation and loss of drag-out, including increasing solution temperature, using ***wetting agents***, reducing the withdrawal rate of parts from solutions, increasing dwell time to permit complete draining, rearranging the position of parts on racks to minimize solution trapping, and using ***recovery rinsing***.

Drag-Out Tank — The drag-out tank is a rinse tank that initially is filled with pure water. As the plating line is operated, the drag-out rinse tank remains stagnant and its chemical concentration increases as more work is processed.

After a period of operation, the solution in the drag-out tank can be used to replenish the evaporative losses to the plating bath. The recovery rate will usually be substantial with baths, such as chromium and nickel plating solutions that are operated at elevated temperatures. Low-temperature baths, such as cadmium or zinc plating solutions, have minimum surface evaporation and the use of a drag-out tank is less effective.

As a rough estimate, drag-out recovery will reduce drag-out losses by 50% or more. The efficiency of the drag-out tank arrangement can be increased significantly by adding a second drag-out tank. Use of a two-stage drag-out system usually reduces drag-out losses by 70% or more. In some cases, multiple drag-out tanks (e.g., three to five tanks) can be used to completely close the loop and return essentially 100% of drag-out. Drag-out tanks can be combined with ***counter-flow rinsing*** to provide both chemical recovery and flow reduction.

Draining/Rinsing Over the Plating Tank — After a rack or barrel is removed from a process tank, the ***drag-out*** drains from the item and returns directly to the bath as long as the item is held over the tank. This simple method of direct drag-out return can be maximized on a hand-operated line by installing a bar over the process line on which the operator can hang a rack or hook. On automatic machines, the unit can be programmed to increase dwell time above the process tank. For barrel operations, the barrel can be rotated over the process tank to help free the drag-out.

Electrodialysis — Electrodialysis technology employs ion-permeable and selective membranes under an applied direct current potential difference to separate ionic species from an aqueous solution. Its primary application for chemical recovery is nickel plating, where it competes with ***recovery rinsing*** (e.g., ***drag-out tanks***), evaporators, and ***ion exchange***. A potential advantage of electrodialysis over other concentrating and return methods of nickel recovery is its ability to selectively retard the recovery of certain organic materials that tend to build up in nickel plating baths, while more freely permitting the transport of a desirable organic bath constituent (saccharin) and nickel salts. This aspect of the process could reduce the frequency of bath purification as compared to other recovery schemes.

Electrolysis — Electrolysis (dummying or dummy plating) is an electrolytic treatment in which metallic contaminants in a metal finishing solution are either plated out (low current density, or LCD, electrolysis) or oxidized (high current density, or HCD, electrolysis).

Dummy plating is applied to a range of plating and other metal finishing processes. The contaminant metals most frequently removed by dummy plating are copper, zinc, iron, and lead. Dummy plating is usually performed using a corrugated steel sheet cathode with an anode-to-cathode spacing of approximately 4 in.

The optimal current density will depend on the metal contaminants being removed. The normal range is 2 to 8 asf. The duration of treatment is typically 2 to 5 amp-hr/gal. Agitation is essential for speedy removal of contaminants and air agitation should be used if the type of bath permits.

LCD dummy plating can be performed on a batch or continuous basis. Batch treatment is usually performed in the process tank and requires downtime. Continuous treatment is usually performed in a side tank, and cathodes are typically sized to permit 0.05 amp of current to flow per gallon of solution. The solution is preferably returned to the process tank through a filter.

HCD electrolysis typically refers to the practice of oxidizing trivalent chromium to hexavalent chromium in chromic acid baths (e.g., chromium plating and chromic acid anodizing). It is also used to gas-off chloride as chlorine. The HCD process requires an anode-to-cathode ratio of between 10:1 and 30:1. Lead or lead alloy anodes are typically used in the process. A lead peroxide film formed on the anode functions as the oxidation agent. Current densities of 100–300 asf are used. The rate of conversion is controlled by the overall cathode and anode areas and current flow.

Electrowinning — Electrowinning is employed in metal finishing facilities to remove metallic ions from concentrated rinse water, spent process solutions, and ***ion exchange*** regenerant.

An electrowinning unit consists of a rectifier and a reaction chamber that houses anodes and cathodes. In the simplest design, a set of cathodes and anodes are placed in the reaction chamber containing the electrolyte. When the unit is energized, metal ions are reduced onto the cathode. The rate at which metal can be recovered (i.e., plated onto the cathode) from solutions depends on several factors, including the concentration of metal in the electrolyte, the size of the unit in terms of current and cathode area, and the species of metal being recovered.

Electrowinning is different from other recovery technologies (e.g., evaporation, ion exchange) in that an elemental metal is recovered rather than a metal bearing solution. The recovered metal is usually not pure enough to be used as anode material in plating processes. More often, it is sold as scrap metal.

Electrowinning is particularly applicable for removing metal from solutions containing a moderate to high concentration of metal ions (>3,000 mg/ℓ). Below 1,000–2,000 mg/ℓ of metal, the conventional electrowinning process becomes very inefficient. Therefore, it is not thought of as a “compliance” technology (i.e., a technology that will meet wastewater discharge standards). Rather its benefit is in recovering valuable metals that would otherwise be converted to metal hydroxide sludge by the wastewater treatment system.

High-surface-area electrowinning, developed during the 1970s and commercialized in the 1980s with the reticulate cathode design, extends the applicability of this technology to low-concentration solutions.

Filtration — Filtration is the most commonly applied method of corrective ***bath maintenance***. It is used to remove suspended solids from plating and other metal finishing solutions. Suspended solids in plating solutions may cause roughness and burning of deposits.

Various equipment is used for filtration, with the most common being cartridge filters and pre-coat (diatomaceous earth) filters. Sand or multimedia filters are also employed. Cartridge filters are available with either in-tank or external configurations, with the former used mostly for small tanks and the latter for larger tanks. Most cartridges are disposable; however, washable and reusable filters are available commercially. Pre-coat filters are used mostly for large tank applications. Filter media are selected based on the chemical composition of the bath.

Filtration systems are sized based on solids loading and the required flow rate (turnovers per hour). Typical flow rates for plating solution applications are two to three bath turnovers per hour.

Flow Meters — By themselves, flow meters and accumulators do not reduce water use. However, they make the metal finisher aware of water use rates and are useful in identifying excessive water use.

These devices are most useful when installed on fresh-water lines feeding individual rinse tanks or, at a minimum, on pipes feeding individual plating lines.

Meter readings taken over an extended time will show trends in water use. Using these data, shop management can identify specific locations where excessive water use occurs and can correct the problem before long-term waste has resulted.

Flow Restrictors — Flow restrictors are inexpensive devices that are connected in line with the tank's water inlet piping to regulate the flow of water through the pipe.

They are typically an elastomer washer that flexes under pressure such that the higher the water pressure, the smaller the hole available for flow passage. Therefore, they maintain a relatively constant flow under variable water pressures.

Flow restrictors are available in a wide range of sizes (0.1 gal/min to more than 10 gal/min). The smaller-sized restrictors are most commonly used with multiple counterflow rinse tank arrangements. The larger ones are commonly used with single overflow rinses. Some restrictors aerate the water as it passes through, in a manner similar to a kitchen faucet (Venturi effect).

Fume Suppressants —Various types of fume suppressants are used to control the evolution of mist from finishing tanks, especially hard chromium plating tanks.

Chromium plating generates hydrogen gas at the cathode and oxygen gas at the anode. The gas bubbles rise to the surface and break, causing the release of a mist. When added to the bath, a certain type of fume suppressant reduces the surface tension of the chromium plating bath from about 72 dynes/cm to between 30 and 40 dynes/cm. When the surface tension is reduced this low, the size of the gas bubbles is reduced, which in turn creates less mist.

Ion Exchange — Ion exchange is a useful technology for recovering plating chemicals from dilute rinse waters. Two common configurations are referred to as metal scavenging and deionization.

Metal scavenging uses only one type of ion exchange resin, either anion or cation, depending on the charge of metal or metal complex being recovered. Because this system does not have both cation and anion resins, the rinse water will not be fully "deionized" and cannot be reused as rinse water for common rinsing purposes.

With the deionization configuration, both anion and cation resins are employed and the rinse water can be recirculated in a closed loop.

With both of these configurations, rinse water containing a dilute concentration of plating chemicals is passed through an anion and/or cation column (or dual columns of the same type) and the metals are removed from the rinse water and held by the ion exchange resin. When the capacity of the unit is reached, the resin is regenerated and the metals are concentrated into a manageable volume of solution. Depending on the chemical nature of the process, the regenerant solution can be returned directly to the plating tank for reuse, further processed and returned, or the metals can be recovered by another technology such as ***electrowinning***.

The most common applications for these configurations of ion exchange are with the recovery of copper, nickel, and precious metals. Ion exchange can also be used for treatment of raw water, purification of plating solutions, wastewater treatment, and wastewater polishing.

Membrane Electrolysis — The primary function of membrane electrolysis, when applied as a ***bath maintenance*** technology, is to lower or maintain, at an acceptable level, the concentration of metallic impurities in plating, anodizing, etching, stripping, and other metal finishing solutions.

This is accomplished through the use of an ***ion exchange*** membrane(s) and an electrical potential applied across the membrane(s). The membranes employed with these technologies are ion-permeable and selective, permitting ions of a given electrical charge to pass through. Cation membranes allow only cations, such as copper, nickel, and aluminum to pass from one electrolyte to another, while anion membranes allow only anions, such as sulfates, chromates, chlorides, or cyanide to pass through.

Bath maintenance units can be configured with only cation or anion membranes or both. The oxidation of Cr^{+3} to Cr^{+6} occurs at the anode, in the same manner as high current density dummy plating. The anode material and/or coating must be properly selected for this reaction to occur.

The most common applications for this technology within the plating industry are the purification of chromium plating (especially hard chromium) and chromic acid anodizing baths.

Microbial Cleaner — A microbial cleaner is a mild alkaline cleaning solution that relies on a population of microorganisms to consume oil that is removed from parts during the cleaning process. By consuming the oil, the microbes extend the useful life of the cleaning bath. The bath operates at relatively low temperatures (104–131°F) and a pH range of 8.8–9.2, which is a viable environment for these microorganisms. The cleaning process actually takes place in two separate operations. First, parts come in contact with the solution and the oil is emulsified by the chemical components of the solution. Second, the oil particles are consumed by the microbes. The consumption of the oil results in the production of a CO_2 byproduct. Excess biomass is separated from the cleaning solution in a clarifier.

Microfiltration — Microfiltration is a relatively new ***bath maintenance*** technology that is applied to alkaline cleaning baths for the removal of oil.

These baths build up concentrations of oil and solids during use. Free oils can be removed by simple skimming, and most solids can be removed by settling and/or cartridge ***filtration***. However, emulsified oils and colloidal solids are not affected by these devices. At some point, the cleaning efficiency of the bath is impaired and the solution is discarded, despite the fact that most of the bath's constituents are still usable. In many cases, heavy-duty cleaners must be replaced once per week.

The microfiltration technology separates the emulsified oils and colloidal from the aqueous cleaning solution, thereby extending the life of the bath. This technology is also applicable to the recovery of cleaning solution ***drag-out*** from rinse waters.

Most commercial microfiltration systems used for this application employ ceramic filter membranes in a crossflow filtration configuration. These membranes are a new development that permits application of microfiltration to solutions and emulsions that are both heated and corrosive. Earlier efforts using polymeric membranes were unsuccessful with this application.

Mist Eliminators — Mesh pad mist eliminators are used to recover plating chemicals that become entrained in the air stream that is exhausted from the surface of a plating tank.

The primary application of this technology is with chromic acid baths, particularly hard chromium plating and chromic acid anodizing. Mesh pad mist eliminators are one of several technologies employed for the removal of plating chemicals from exhausted air. The other two technologies include liquid ***scrubbers*** and chevron mist eliminators. Of the three technologies, mesh pad mist eliminators are considered to be the most efficient.

Typically, a separate mist eliminator is used for each plating tank, although different configurations are possible. Mesh pad mist eliminators are installed within the exhaust system ductwork, as near to the exhaust hood as practical. The mist eliminator enlarges the cross-sectional area of the duct, which causes a reduced air stream velocity within this section. The reduced velocity permits the entrained droplets of plating solution to impinge on and adhere to the mesh pads, thus removing them from the air stream. Having multiple pads in series increases the removal efficiency of the process. The accumulated plating chemicals are periodically washed from the pads, usually accomplished with an integral water spray system. The liquid from pad washing drains to the bath.

Porous Pot — The porous pot is one of a number of products that fall into the ion transfer technology category and are used for maintaining chromic acid baths (e.g., hard chromium and chromic acid anodizing).

The basic ion transfer technology involves the use of a membrane, typically a porous ceramic pot or a polyfluorocarbon membrane (e.g., Teflon®). The unit consists of an electrolytic cell with an anode and cathode (or sets of each) that are separated by the membrane. When energized, trivalent chromium present at the anode is oxidized to hexavalent chromium, and cations (e.g., dissolved iron) present in the anolyte migrate through the membrane into the cathode compartment. The catholyte is periodically discarded and the cathode cleaned of any deposits.

Two important restrictions should be noted for the ion transfer technology.

1. First, this technology should be considered as a ***bath maintenance*** method and not a means of quickly rejuvenating a spent bath. Chromic acid baths that are laden with dissolved metal contaminants will take months to correct with ion transfer and a significant volume of chromium waste can be generated in the process. The correct application of this technology is as a continuous maintenance method that is first applied before the bath is overly contaminated.
2. Second, the ion transfer technology is not practical as a bath maintenance method where the desired tramp metal contamination level (excluding consideration of Cr^{+3}) is less than 4 g/ℓ. To reach a lower point would require frequent changes of the catholyte solution, resulting in a very high waste volume.

Reactive Rinsing — Reactive rinsing is one of several terms that describe rinsing methods that reuse rinse water without any intermediate treatment or recovery steps.

Reactive rinsing refers to cases where a chemical reaction takes place as a result of reusing rinse water for multiple purposes. An example is reusing the rinse water from acid cleaning as rinse water following alkaline cleaning. In this case, the acid rinse water helps to remove the viscous alkaline film remaining on a part after alkaline cleaning.

A similar method, *cascade rinsing* refers to the practice of reusing rinse water multiple times in different rinse tanks for succeedingly less critical rinsing. An example is the use of rinse water from electroplating for rinsing following acid dipping.

Use of either reactive rinsing or cascade rinsing can result in unwanted chemical reactions. For example, reusing the acid dip rinse water in the alkaline cleaning rinse may result in the precipitation of solids.

Dual-purpose rinsing refers to the practice of using the same rinse tank for rinsing parts after they emerge from various process tanks. Its application is only practical in smaller shops with manual or hoist lines. Dual-purpose rinsing can provide essentially the same results as cascade and reactive rinsing, but uses fewer rinse tanks. Often, using dual-purpose rinsing means transporting a dripping rack/part over a considerable distance. This can result in dripping onto floors and/or the accidental contamination of other tanks.

Recovery Rinsing (and other methods of direct ***drag-out*** return) **—** Before they purchase commercial recovery equipment such as ion exchangers and evaporators, metal finishers usually implement uncomplicated methods of drag-out recovery that require much less capital and are simpler to operate. After using these methods and establishing new drag-out conditions, the finisher can consider the applicability of additional recovery such as commercially available units.

Direct drag-out return methods include: draining over the tank, use of air knives, and recovery rinsing, which refers to a category of rinsing methods that result in direct recovery of solution drag-out. The most common recovery rinsing methods is use of a ***drag-out tank***. Other common methods include ***drag-in/drag-out rinsing*** and ***spray rinsing*** over the process tank.

Reverse Osmosis — Reverse osmosis (RO) is a separation process that has been employed in the metal finishing industry to purify raw water (e.g., city water) before use as rinse water, to recover plating chemicals from rinse water, and to polish wastewater treatment effluents (usually for reuse as rinse water).

As a recovery technology, RO has been applied to a range of processes, including: brass, chromium, copper, nickel, tin, and zinc plating solutions, with nickel recovery being the most frequent and successful.

The RO process is designed to operate continuously. The RO membrane is enclosed in a pressure vessel and the feed stream is pumped through the vessel under pressure, at 400 to 1,000 psig, where it is separated into a clean water permeate stream and a concentrated chemical stream by selective permeation. Different types of RO membranes are used (tubular, spiral wound, and hollow fiber), the selection of which depends mostly on the applications and, in particular, on the plating bath chemistry. The most common RO membranes are the hollow fiber and spiral wound configurations.

Scrubbers — A scrubber is an air pollution control device used in metal finishing facilities for reducing vaporous emissions of water-soluble acids. The most common type is the wet packed-bed scrubber. The most effective designs are either crossflow (horizontal) or counterflow (vertical).

In operation, an air stream travels through shop’s ventilation ducts and enters the scrubber. An enlarged cross-sectional area of the scrubber reduces the velocity of the air. The air passes through packing media that is continuously sprayed with recirculated scrubber solution. The water-soluble acids are transferred from the air stream to the scrubber water by the process of absorption. With most designs, the air then passes through a ***mist eliminator***, which is present to prevent droplets of scrubbing solution from re-entraining acid into the exhaust stack. Scrubber water is periodically removed (blowdown) and treated.

Spray Rinsing — Spray rinsing is employed in various manners to reduce ***drag-out*** losses and rinse water use.

Spray rinsing over process tanks provides direct recovery of drag-out. Spray rinse tanks can be used as ***drag-out tanks***, single rinses, or multiple rinses. A common use of spray rinsing is to substitute a spray rinse tank for an overflow rinse tank.

Depending on the part configuration, spray rinsing generally uses from one-eighth to one-fourth the amount of water that would be used for equivalent dip rinsing. Spray rinsing is most effective for flat-surfaced parts and is less effective with recessed and hidden surfaces.

Timer Rinse Controls — Timer rinse controls consist of a pushbutton switch, a timer mechanism, and a solenoid valve.

These units operate in a manner similar to ***conductivity controls***; however, rather than regulating rinse water flow on the basis of rinse tank water quality, the timer rinse controls simply turn water on and off based on a preset time interval.

In operation, a plater lowers parts into the rinse tank and pushes a button (alternatively, a momentary switch could be used that is activated by lowering a rack or barrel). The button or switch activates a timer and opens the solenoid valve for a preset time period. After that time has expired, the solenoid valve closes automatically.

Vacuum Evaporator — A vacuum evaporator is a distilling device that vaporizes water at low temperatures when placed under a vacuum. The rate of vaporization is directly related to the level of the vacuum and the temperature of the solution.

In operation, heated solution is introduced into the vacuum chamber. The vacuum reduces the boiling point of the solution and the resultant vapor (distilled water) is removed from the chamber. The vapor can be either discharged or can be condensed for return to the process (e.g., as rinse water).

Vacuum evaporation systems are relatively complex and are therefore more expensive to construct and maintain than the more simple atmospheric systems. Several types of vacuum evaporators are used in the plating industry: rising film, flash type, and submerged tube. Generally, each consists of a boiling chamber that is under a vacuum, a liquid/vapor separator and a condensing system. Site-specific conditions and the mode of operation influence the selection of one system over another.

Wetting Agents — A wetting agent is a substance, usually a surfactant, which reduces the surface tension of a liquid, causing it to spread more readily on a solid surface.

A typical plating bath solution has a surface tension close to that of pure water at room temperature, about 0.0050 lb/ft. Adding very small amounts of surfactants can reduce surface tension considerably—to as little as 0.0017 to 0.0024 lb/ft. Further additions of the wetting agent will not lower the surface tension appreciably beyond this point.

For years, wetting agents have been used in process solutions to aid in the plating process. These substances are used, for instance, in bright-nickel plating to promote disengagement of hydrogen bubbles at the cathode. They are also used as an aid to ***drag-out*** reduction.

Chapter 4. Roadmap

The purpose of this chapter is to describe a vision for the environmental performance of the metal finishing industry in the near-term future, and to see how that vision might be realized.

The word “vision” can be used in a utopian sense, a picture of how the world might be “if only…” That is not the purpose here. We aim to set a goal and to create a way forward for the metal finishing industry that is achievable by business, reasonable for the regulatory agencies, and acceptable to the public.

We will use a roadmapping technique developed at the National Center for Manufacturing Sciences (NCMS). An NCMS roadmap is a “topographical” roadmap. Like any roadmap, once you know your starting point and have selected a destination, it shows you the alternative routes that take you there. But an NCMS roadmap is distinct in that it asks not only “how far?” but also “how steep?” This approach will help us make realistic choices as we explore alternative destinations and pathways. Some promising-looking roads become blind alleys, and others have unrealistically steep segments. The roads we ultimately recommend are those that appear to us, on the basis of what we have learned from the benchmarking results, to be the optimal paths to the right end.

With the benchmarking results at our disposal, we have been able to extend some of our recommendations down to the level of process-by-process detail. For the metal finishing sector, with its diverse mix of processes, a roadmap has to be specific to be useful. But one size cannot fit all. The best technology for one shop may not make sense for another with a different process mix, operating under different business conditions.

Thus, this roadmap is intended as a guide, not a prescription. With that understanding, we begin with an outline of the method and some general considerations, proceed toward more specific applications, and end with a summary of our best guess at the right way forward.

4.1 Method Outline

An NCMS “topographical roadmap” begins by posing four questions:

1. Where are we? (Point A)
2. Where do we want to go? (Point B)
3. How will we get there? (How far?)
4. What will it take? (How steep?)

The Benchmarking Survey Phase 1 results in Chapter 1 form the basis for our Point A, and the company rankings in Chapter 2 give us some indication of where we can set a realistic Point B. And the Guide to Best Practices in Chapter 3 offers us some explicit pathways for getting from Point A to Point B. The examples set by the top-performing companies demonstrate what can be attained under favorable conditions.

But question 4 will help us avoid an all-too-common mistake. The fact that Company X can perform at a given level on some specific benchmark does not mean that Company Y can, or even should, do so. There are many factors to consider. There are often trade-offs involved: using an evaporator to reduce wastewater discharge can increase energy usage, for example.

It is useful to note here that the “landscape” that we are roadmapping is more constrained than one we might encounter on a physical map. Real ridges, valleys, and passes can take on just about any shape. But the choices we are mapping are interdependent, giving the “landscape” some characteristic features that can limit the available pathways. If we know that moving “downhill” toward reduced water use forces us (given certain technology choices) to move “uphill” in the energy direction, we can use that information to find the best available path. Also note that we have more “directions” at our disposal than does a traveler on a two-dimensional surface. Thus, for instance, in the water flow example, the possibility of automatic flow controllers gives us a dimension to explore that is virtually independent of the energy axis.

Along with these technology-based constraints on our landscape, we should also note that yet another element of choice applies that is not ordinarily encountered in geographical mapping. Simply expressed, policy can “move mountains.” Choices made by regulators can dramatically change the calculations. Consequently, we offer some remarks on regulatory policy, in the hope that informed choices are likely to encourage, rather than impede, progress toward our targets.

While the “space” we are moving in is metaphorical, time—real time—goes on. A target schedule for reaching our destination, and for getting to milestones along the way, would be a useful addendum to this roadmap. Evaluating the vision in the context of a set schedule provides a good test of practicality.

4.1.1 Starting Point

To represent the starting point, we can use the information summarized in Tables 1-9, 1-10, and 1-12 to find a statistical summary of overall industry performance (as reflected in our data set) for the three basic environmental performance measures listed below, where each measure is normalized per dollar of sales:

- Water use
- Sludge generation rate
- Electricity use.

Other performance measures were also summarized in Chapter 1, but we will not attempt to set target performance levels for them. In the case of total energy usage, we saw too much inconsistency in the data as reported to feel confident in using it, as explained in Chapter 1.

The reasons for omitting the other measures require a bit more explanation.

We do not treat organic chemical emissions in detail because that target is simply zero in all cases. Many companies have phased out the use of volatile organic cleaners and solvents completely, and we believe that this goal can be realized for virtually all applications with existing substitutes.

Hazardous sludge shipped to landfills would potentially be another good candidate performance metric. Metal finishers who have arranged for their sludge to be recycled are certainly doing better environmentally than those who landfill their sludge. However, it is preferable from an environmental standpoint not to generate the sludge in the first place, and that should be the prime focus of improvement efforts. Also, the availability of recycling facilities is largely determined by factors that metal finishers are not in a position to influence. We have, therefore, chosen to concentrate on total sludge generated, and to treat recycling as a useful, but secondary consideration.

Tables 1-9, 1-10, and 1-12 list the average industry performance levels on each of the three performance measures separately for six major plating processes:

- Zinc Plating
- Nickel Plating
- Decorative Chromium Plating
- Electroless Nickel Plating
- Anodizing
- Hard Chromium Plating.

For other processes, we do not have enough data to compute statistical averages, so it is hard to set numerical starting points. (Readers can use representative data points appearing in the overall data summary in Chapter 1, Appendix 1B, to form a general idea of the performance of a few representative facilities running these processes.)

The information in Chapter 1 provides a fair approximation of what the industry is doing. We now turn to the question of what we *can* do.

4.1.2 Destination

Let us be candid. Setting targets is a risky business.

First, the usual potential embarrassments can arise whenever one makes assumptions about conditions in the future. Changes in technology, or in business conditions, can make seemingly reasonable objectives look pretty wide of the mark in retrospect.

But perhaps more worrisome in the present context is the potential for misuse. Is it possible that the benchmark targets laid out in this section will find themselves inappropriately codified into rules? One of the most difficult tasks facing a regulatory agency is the setting of appropriate emissions limits. Here, we have a study that provides the most comprehensive view available of the current state of environmental performance for the metal finishing industry. We are about to suggest process-by-process target performance levels. Won't there be a natural tendency to seize on target values that may have an apparent aura of statistical validity and use them as the basis for rule making, as if they were somehow sanctioned by industry practice?

We do not believe that to be an issue in this case, for the following reasons:

- The performance metrics that we are dealing with, resource usage and sludge generation rates, are not typically regulated quantities. One cannot go from these targets to emission levels without additional information not available from this study, such as rates of metal utilization and day-to-day (rather than annual average) process mix.

- The target performance levels deduced in the following sections, while useful for benchmarking purposes, do not have the kind of statistical validity needed for rule making. The main difficulty lies in determining top performance on a process-by-process basis from the available data. As discussed in Chapter 1, most shops do not keep resource use and waste generation data for individual processes. We were able to use statistical methods to deduce *average* performance levels for the six most common processes. But, in this chapter, we are not looking for average levels—we are looking for the best. A special estimation procedure, plus an element of subjective judgment, is unavoidable in proceeding from the available data to performance targets.

- Rules must be specific, and they must be exact. (It is very difficult to enforce a fuzzy standard.) Rules must also apply equally to everyone. But the types of environmental performance levels suggested here cannot be applied universally. Not every shop will be able to attain the target levels, even in principle. Differences in part configurations, product specifications, operating schedules, and many other factors can influence the final outcome. Since we are using these targets as benchmarks rather than as inflexible rules, such shop-to-shop differences can be taken into account in setting goals. The targets can provide a good place to start. They do not have to represent immovable hurdles. Business decisions can be, and generally are, based on best guesses, subjective weightings, and the freedom to ignore the data and go with intuition. Such an operating mode can be advantageous for an entrepreneur. But a regulator who chose to ignore the data and go with intuition would be on shaky ground, to say the least.

Thus, we are confident that these targets will function as "carrots" rather than "sticks."

With this preamble, we will explain in the balance of this section how we will use the results of Chapter 1, and adapt the methods of Chapter 2, to develop benchmark performance targets for several processes. The individual processes are considered in detail in subsequent sections.

The basic idea behind our approach is straightforward: determine the present performance level for each company in the database carrying out a given process, and set the target level at that achieved by the top 25% of companies. This procedure guarantees that the targets are achievable in practice, at least under favorable circumstances, using currently available technology.

However, as discussed in Chapter 1, determining top performance levels from the available data *for individual processes* presents difficulties. Except for facilities that run only one type of process, we have no information on how much of the total reported discharge is attributable to each specific process.

Thus, for most shops, we need to find a way to estimate the contribution from each process. In what follows, we assume that the *proportion* of wastewater due to each process is the same as would be expected in an average shop. In other words, we assume that a good performer tends to be uniformly good across the board, not just in one or two processes.

Of course, this approximation will not always hold. A company might have made a substantial capital investment for just one process, for example. It is also likely to be less accurate for processes that represent just a small fraction of a company's total operations. However, it should be sufficiently accurate to set realistic targets.

For each of the three performance measures and each of the six metal finishing processes, we establish a target level as follows:

- We use the "industry average" estimation procedure to find the performance level for each company operating the process for which we have data.
- We list the performance level of all the companies in a table, ordered from best to worst performance. (We include the industry average in the table for comparison.)
- We divide the table into quartiles, with the top-performing 25% of companies in the first quartile, etc.
- We set the benchmark target level as the level required to reach the performance of companies in the first quartile.

The benchmark levels are summarized for all processes in three tables (one table for each performance measure) in Section 4.3. These tables also indicate the percentage improvement that would result if the average industry performance were raised to the benchmark level.

4.1.3 Factors Affecting "How Far"

Once we have determined where we want to go, we need to consider what paths will take us there. Simply knowing start and end points does not determine the length of a path. There are generally alternative routes to follow, and the most direct is not necessarily the optimal road to travel.

In the cases we are considering here (improving efficiency and reducing waste in metal finishing processes), there are two primary alternatives: one involves capital investments in advanced technology, upgraded equipment, or facilities improvements; the other involves operational changes, including items such as work practices, operator training, scheduling, and worker suggestion and incentive programs. They are, of course, not exclusive. The best path may involve elements of both, and the best combination for one shop will differ from what is best for another.

A key question for either path is "how far" an equipment or operational change will take a facility along the road to greater efficiency or waste reduction. In other words, what is the anticipated reduction in usage or waste due to a given change? The cost of instituting the change can then be balanced against the anticipated savings. The problem for most facilities is that they do not have the process-by-process data that would allow them to carry out this calculation. However, the industry averages given here may help generate reasonable estimates.

The Guide to Best Practices in Chapter 3 provides a starting point for companies plotting a course toward improved performance (and consequent environmental cost savings). One striking observation is the extent to which fairly straightforward changes in work practices, combined with inexpensive equipment (flow control meters and rinse water conductivity monitors, for example) can potentially result in both environmental improvement and in cost savings for a wide variety of metal finishing processes. Heavy capital costs are no barrier to improvements of this type, and the potential savings are significant. (One of the main reasons why companies have not universally taken advantage of these opportunities is probably related to the fact that typical accounting methods do not clearly indicate the degree to which environmental costs are avoidable.) As more companies become familiar with the facts presented here, we can anticipate that many will make the simple changes and reap the benefits.

More substantial changes, such as altering the configuration of rinse tanks, involve a somewhat greater degree of investment and disruption of ongoing activities. Nevertheless, the potential for substantial savings as indicated in Chapter 2 should be sufficient inducement to send many companies down this path to improvement. Developing alternative processes is more difficult still. Yet companies with an eye to the future will be putting a steady amount of effort in phasing out yesterday’s materials and processes and phasing in tomorrow’s. They are the companies that will still be in business when tomorrow has arrived.

4.1.4 Factors Affecting “How Steep”

In performing the cost-benefit estimates indicated in the preceding section, it is essential to understand the level of resources (cost of equipment, cost and time for worker training, etc.) needed to move along the chosen improvement path. This is one element of the “how steep” question. The regulatory environment is another key factor in shaping the landscape traversed by the road to improvement. In this section, we provide a brief discussion of both factors, and conclude with a look at an important way in which one can influence the other.

4.1.4.1 Cost

The benchmarking study was not designed to capture capital costs for equipment upgrades. Such studies have been carried out in the past (see, for example, *Pollution Prevention and Control Technology for Plating Operations**). One lesson learned from that study is that the best source of information for capital costs is suppliers, rather than users, of the equipment, and suppliers were not included in the benchmarking study. It would be useful to supplement this information with an updated, comprehensive survey of equipment costs.

4.1.4.2 Regulatory Policy

Regulatory policy—including both the way the rules are written *and* how they are applied—can significantly affect how easy it is for companies to make the changes needed for better environmental performance. Well-crafted and well-implemented rules can provide incentives for pollution prevention approaches. Conversely, shortsighted regulatory policy can create, and in some unfortunate cases has created, formidable barriers to improvement.

This study deals primarily with technical issues, and was not designed to answer questions concerning the implications of regulatory policy. However, some of the study results may be useful to those responsible for formulating or implementing regulations. The following observations are intended to help encourage industry and regulators to pull in the same direction toward the shared goal of improving resource efficiency and mitigating environmental impact.

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* Cushnie, George. *Pollution Prevention and Control Technology for Plating Operations.* National Center for Manufacturing Sciences, Ann Arbor, MI. 1994.

One of the most significant regulatory issues affecting wastewater discharge is the potential for using *mass-based* discharge standards in place of *concentration-based* standards. Most facilities are now regulated according to the concentrations of specific metals appearing in the wastewater. Improving in water usage rate, resulting in less water discharged for the same amount of metal, can raise the concentrations. As a result, existing regulations can present a significant disincentive to improvement in water conservation.

An alternative method for setting the standard is to limit the total amount of metal discharged, regardless of the volume of water. This would seem to be a win–win situation, resulting in conservation of water resources with no additional impact on the watershed. What stands in the way of widespread use of this option?

The problem is that it is more difficult to regulate according to a mass-based standard. A concentration limit can be set for any facility, regardless of the scale of its operation. But a mass-based standard requires some fair way of determining the limit to be imposed. It is similar to the "apples-with-apples" problem discussed in Section 1.3.1. If the discharge limit is to be based on the size of the company, how should the production volume (the "denominator") be measured? Sales numbers tend to be readily available, but depend on economic factors extraneous to environmental considerations. Surface square foot numbers are technically more suitable, but are often difficult to compute.

But well-motivated companies and regulatory agencies can work together to develop reasonable approaches for dealing with these difficulties. Here is an example.

Among the possible denominators discussed in Chapter 1, there will typically be one that is appropriate and acceptable for a company's operations. The company can agree to maintain the necessary records, and the agency can agree to calculate a mass-based standard scaled by that denominator, by a method such as the following:

- Take a representative time period for which the denominator and the total water discharged by the operation is known.
- Multiplying the total discharge by the concentration limit in effect for the facility gives the mass limit that would have applied to the facility.
- Dividing the mass limit by the denominator gives an appropriately scaled mass limit for future operations.

The company would then monitor the production volume and the total mass discharged an ongoing basis. As long as the mass per production volume were below the limit, the company would be free to reduce water usage as much as possible.

As shown in Chapter 2, water use reduction can result in substantial savings for the company. This fact alone might provide sufficient incentive to undertake any additional record keeping necessary to measure production volume according to the agreed-upon denominator.

The incentive for the regulatory agency may be the more difficult problem. Regulatory agencies typically consider it part of their mandate to impose burdens, but have generally been less eager to accept burdens, even when to do so might ultimately advance their underlying mission. In this regard, it might be useful to develop the habit of applying cost–benefit calculations to regulatory policy, where the benefit is defined with respect to the public and the environment. This would be in keeping with the promise of government "reinvention." A policy of greater flexibility in matters such as mass-based regulation offers the opportunity for substantial dividends.

4.1.4.3 Regulatory Policy and Cost

In addition to setting emissions limits, regulation also imposes costs. The direct and indirect effects of these costs themselves have environmental consequences. We conclude this section with a suggestion on how the costs can have a positive, rather than a negative, effect on the environmental performance of regulated facilities.

The prescription is simple:

- Avoid imposing costs that interfere with a company's ability to improve its environmental performance.
- When costs are imposed, allow the company to reduce the costs by improving its environmental performance.

One way to implement this prescription practice is to provide an alternative regulatory pathway for companies that demonstrate a commitment to continual environmental improvement. Instead of simply meeting a set of prescribed standards, companies could be allowed to fulfill their compliance requirements by adopting a set of best practices and demonstrating their adherence to them. Voluntary "beyond compliance" programs such as the Strategic Goals Program can serve as test beds for developing ways in which performance standards can be established to the satisfaction of both industry and regulatory agencies.

This type of pathway might well prove to be the smoothest and straightest road to real environmental improvement for the metal finishing industry, and for other sectors as well.

4.2 Specific Process Benchmarks

In the following section, we develop benchmark performance levels for specific metal finishing processes.

4.2.1 Zinc Plating

4.2.1.1 Wastewater

The regression analysis of Chapter 1 indicated that zinc plating accounted for the highest level of wastewater discharge of the six processes analyzed. At 4.79 gal/$ sales, zinc consumed over twice as much water per dollar as the next-most water-intensive process (decorative chromium). Some of this difference is no doubt due to the relatively lower dollar value of zinc plating, but even with that fact taken into account, improvement in water conservation for zinc processes represents a major opportunity for improvement.

Sixty two companies in the database reported doing at least some zinc plating. Table 4-1 lists the value of wastewater discharged per sales dollar due to zinc plating. We also list the proportion of the company's sales from zinc plating.

To perform as well as companies in the top quartile, the wastewater discharge from zinc plating must be less than 2.5 gal/$ sales. This would represent an improvement of 48% over the current industry average of 4.79 gal/$ sales.

4.2.1.2 Sludge Generation

Zinc plating, particularly barrel plating, is also the greatest contributor to sludge generation of the six processes analyzed in Chapter 1. Zinc barrel plating contributes an average of 0.054 lb of sludge per sales dollar, and zinc rack plating 0.016 lb/$ sales, on a dry weight basis.

We have data on 48 companies that carry out at least some zinc barrel plating (see Table 4-2). A company performing as well as those in the top 25% of companies in our database could generate no more than 0.017 lb of sludge per dollar of sales from the zinc barrel process.

Raising the average performance level of companies to this level would represent a 69% improvement over current levels.

Note, however, that most of the companies in the top quartile have a rather small percentage of their sales from zinc barrel plating, indicating that the estimate might be inaccurate.

Table 4-1. Wastewater Discharge From Zinc Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	**gal/$ sales**	**Share of Sales, %**	**ID**	**gal/$ sales**	**Share of Sales, %**	**ID**	**gal/$ sales**	**Share of Sales, %**	**ID**	**gal/$ sales**	**Share of Sales, %**
123	0.06	43.2	57	2.58	71.0	**av**	**4.79**		20	7.54	10.0
119	0.50	10.0	120	2.79	90.0	93	4.86	72.0	132	7.81	13.3
107	0.98	50.0	58	2.82	5.0	36	4.95	89.0	52	8.02	36.0
21	1.04	74.0	7	3.00	100.0	38	5.00	10.0	138	8.05	33.0
127	1.12	69.7	73	3.02	69.0	72	5.21	59.0	109	8.16	90.0
117	1.26	20.0	142	3.59	100.0	50	5.21	46.0	74	8.16	38.0
112	1.39	100.0	126	3.66	20.0	144	5.58	10.0	31	8.93	100.0
113	1.41	35.2	114	3.99	88.0	115	5.61	45.0	106	9.08	25.0
29	1.73	100.0	87	4.07	73.0	98	5.71	100.0	71	9.49	36.0
59	2.07	43.0	145	4.10	100.0	65	6.00	34.0	39	9.97	23.0
23	2.07	100.0	101	4.37	70.0	133	6.19	95.0	46	10.51	19.0
53	2.10	7.0	104	4.48	40.0	110	6.44	95.0	105	10.58	50.7
48	2.23	53.0	43	4.49	59.0	27	6.45	100.0	14	11.60	30.0
51	2.31	89.0	37	4.73	95.0	44	6.65	5.0	60	11.69	97.0
47	2.39	65.0	8	4.77	100.0	140	7.04	13.6	141	11.82	15.0
81	2.46	43.0				122	7.45	40.0	79	12.44	52.0

Table 4-2. Sludge Generation From Zinc Barrel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	**lb/$ sales**	**Share of Sales, %**	**ID**	**lb/$ sales**	**Share of Sales, %**	**ID**	**lb/$ sales**	**Share of Sales, %**	**ID**	**lb/$ sales**	**Share of Sales, %**
73	0.0000	13.8	65	0.0173	21.4	38	0.0283	4.0	**av**	**0.0542**	
123	0.0000	9.5	59	0.0174	43.0	23	0.0288	60.0	101	0.0561	17.1
58	0.0000	5.0	120	0.0180	90.0	72	0.0295	13.0	29	0.0578	100.0
43	0.0000	3.0	110	0.0197	38.0	107	0.0318	2.5	79	0.0618	33.0
48	0.0033	26.5	8	0.0220	50.0	60	0.0340	53.4	114	0.0696	66.0
53	0.0048	1.8	52	0.0238	10.8	31	0.0350	65.0	44	0.0715	2.5
141	0.0053	0.1	126	0.0246	20.0	145	0.0366	50.0	132	0.0765	6.7
46	0.0056	7.6	127	0.0252	52.3	140	0.0386	11.2	36	0.0903	24.0
119	0.0064	0.5	20	0.0255	5.0	14	0.0386	15.0	39	0.0932	11.5
138	0.0097	19.8	106	0.0256	23.8	133	0.0421	95.0	81	0.1132	43.0
117	0.0119	2.0	109	0.0257	87.3	51	0.0482	22.3	104	0.1200	19.2
57	0.0166	3.6	47	0.0258	19.5	37	0.0510	95.0	87	0.1235	73.0
						93	0.0519	37.4			

However, we do have data from a few companies in the second quartile with a substantial proportion of their sales from the zinc barrel process, indicating that the target level is at least approachable. (We also have a number of companies whose zinc barrel operations generate substantially more sludge than average, causing the average to appear well below the median performance level.)

Data on sludge generated in zinc rack operations is presented in Table 4-3. The industry average is 0.0164 lb/$ sales. Of the 50 companies reporting zinc rack data, the top quartile generated 0.0075 lb of sludge or less per dollar of sales. Improving the average industry performance to that level would represent a 54% improvement.

Table 4-3. Sludge Generation From Zinc Rack Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	**lb/$ sales**	**Share of Sales, %**	**ID**	**Lb/$ sales**	**Share of Sales, %**	**ID**	**lb/$ sales**	**Share of Sales, %**	**ID**	**lb/$ sales**	**Share of Sales, %**
43	0.0000	56.1	57	0.0090	67.5	47	0.0139	45.5	140	0.0208	2.4
73	0.0000	55.2	7	0.0090	100.0	71	0.0141	36.0	14	0.0208	15.0
123	0.0000	33.7	65	0.0093	12.6	38	0.0152	6.0	27	0.0248	100.0
48	0.0018	26.5	110	0.0106	57.0	23	0.0156	40.0	51	0.0260	66.8
53	0.0026	5.3	112	0.0109	100.0	72	0.0159	46.0	93	0.0280	34.6
141	0.0028	14.9	144	0.0109	10.0	**av**	**0.0164**		101	0.0302	52.9
46	0.0030	11.4	8	0.0119	50.0	107	0.0172	47.5	79	0.0333	19.0
113	0.0031	35.2	52	0.0128	25.2	142	0.0173	100.0	114	0.0375	22.0
119	0.0035	9.5	127	0.0136	17.4	60	0.0183	43.7	50	0.0376	46.0
138	0.0052	33.4	20	0.0138	5.0	74	0.0187	38.0	44	0.0385	2.5
117	0.0064	18.0	106	0.0138	1.3	31	0.0189	35.0	132	0.0412	6.7
122	0.0075	40.0	109	0.0139	2.7	21	0.0189	74.0	36	0.0487	65.0
						145	0.0197	50.0	39	0.0503	11.5

4.2.1.3 Electricity Use

In terms of electricity use, zinc is second to hard chromium plating. Zinc consumes 0.514 kWh/ $ sales.

We have electricity data for 53 companies, as summarized in Table 4-4. Performance in the top quartile would require consumption below 0.320 kWh/$ sales, an improvement of 37% over current levels.

Table 4-4. Electricity Usage Rate for Zinc Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	**kWh/$ sales**	**Share of Sales, %**	**ID**	**kWh/$ sales**	**Share of Sales, %**	**ID**	**kWh/$ sales**	**Share of Sales, %**	**ID**	**kWh/$ sales**	**Share of Sales, %**
117	0.180	20.0	37	0.330	95.0	123	0.456	43.2	132	0.658	13.3
48	0.180	53.0	98	0.344	100.0	109	0.467	90.0	145	0.660	100.0
142	0.246	100.0	71	0.353	36.0	53	0.467	7.0	120	0.666	90.0
58	0.252	5.0	65	0.369	34.0	122	0.479	40.0	133	0.680	95.0
113	0.261	35.2	59	0.379	43.0	**av**	**0.514**		140	0.688	13.6
39	0.265	23.0	110	0.380	95.0	107	0.544	50.0	74	0.736	38.0
127	0.278	69.7	105	0.384	50.7	79	0.576	52.0	14	0.769	30.0
126	0.291	20.0	27	0.385	100.0	43	0.581	59.0	47	0.788	65.0
21	0.294	74.0	23	0.389	100.0	138	0.592	33.0	50	0.792	46.0
144	0.314	10.0	114	0.406	88.0	46	0.613	19.0	81	0.815	43.0
106	0.315	25.0	44	0.422	5.0	36	0.614	89.0	93	0.829	72.0
52	0.319	36.0	104	0.423	40.0	38	0.634	10.0	101	0.888	70.0
31	0.320	100.0	72	0.436	59.0	87	0.646	73.0	60	0.891	97.0
						57	0.653	71.0	141	1.322	15.0

4.2.2 Nickel Plating

4.2.2.1 Wastewater

The industry average wastewater discharge rate is 1.99 gal/$ sales. Table 4-5 summarizes the performance of each of the companies in the database carrying out nickel plating. Thirty-three companies report some nickel operations.

To perform at the level of the top quartile, a company would have to achieve a wastewater discharge of no greater than 0.5 gal/$ sales. If the industry average were brought to that level, it would represent an improvement of 75% over the current average.

4.2.2.2 Sludge Generation

The industry average rate of generation of sludge per sales dollar from nickel plating is 0.0066 lb/$ sales. We have 32 companies who submitted data on sludge generation from nickel plating. As shown in Table 4-6, the top quartile generated no greater than 0.0018 lb/$ sales.

Improving the industry average to the level of the top quartile would amount to an increase of 73%. This is an aggressive target, but at least one company with 100% nickel plating operations (and thus independent of our estimation procedure) has done even better, and several other companies indicate comparable levels. We believe it is an achievable, if challenging, target.

4.2.2.3 Electricity Use

On average, companies in our database use 0.453 kWh to generate each dollar of sales from nickel plating. Table 4-7 shows data from 33 companies.

Table 4-5. Wastewater Discharge From Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %
13	0.00	79.0	134	0.54	61.0	47	0.99	5.0	44	2.76	17.0
119	0.21	20.0	54	0.56	10.0	69	1.01	3.0	140	2.92	16.3
149	0.37	15.0	113	0.59	5.8	126	1.52	14.0	67	3.17	66.0
147	0.39	5.0	148	0.70	20.0	43	1.86	14.0	109	3.39	6.0
107	0.41	5.0	121	0.70	6.0	**av**	**1.99**		106	3.77	10.0
146	0.44	6.0	59	0.86	35.0	96	2.04	10.0	39	4.14	13.0
127	0.47	10.0	53	0.87	5.0	38	2.08	10.0	64	4.93	23.0
117	0.52	14.0	48	0.93	5.0	56	2.48	65.0	34	7.77	25.0
			86	0.95	100.0	76	2.51	95.0			

Table 4-6. Sludge Generation From Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %
64	0.0000	23.0	149	0.0019	15.0	121	0.0038	6.0	107	0.0090	5.0
43	0.0000	14.0	54	0.0020	10.0	59	0.0049	35.0	147	0.0090	5.0
48	0.0009	5.0	13	0.0021	79.0	**av**	**0.0066**		146	0.0093	6.0
86	0.0013	100.0	96	0.0022	10.0	126	0.0069	14.0	140	0.0109	16.3
53	0.0013	5.0	69	0.0030	3.0	127	0.0071	10.0	67	0.0127	66.0
148	0.0016	20.0	134	0.0031	61.0	106	0.0072	10.0	44	0.0202	17.0
113	0.0016	5.8	56	0.0033	65.0	109	0.0073	6.0	39	0.0264	13.0
119	0.0018	20.0	117	0.0034	14.0	47	0.0073	5.0	76	0.0294	95.0
						38	0.0080	10.0			

Table 4-7. Electricity Usage Rate for Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %
34	0.000	25.0	113	0.228	5.8	149	0.304	15.0	147	0.428	5.0
119	0.000	20.0	39	0.231	13.0	59	0.331	35.0	**av**	**0.453**	
54	0.000	10.0	127	0.243	10.0	56	0.366	65.0	107	0.476	5.0
117	0.157	14.0	126	0.254	14.0	44	0.368	17.0	148	0.476	20.0
48	0.157	5.0	134	0.263	61.0	67	0.370	66.0	43	0.507	14.0
121	0.158	6.0	106	0.275	10.0	109	0.408	6.0	38	0.553	10.0
13	0.182	79.0	69	0.281	3.0	53	0.408	5.0	140	0.601	16.3
64	0.228	23.0	146	0.301	6.0	96	0.415	10.0	47	0.688	5.0
						76	0.417	95.0	86	0.999	100.0

To achieve the same efficiency in energy usage as companies in the top quartile, a company would have to consume less than 0.228 kWh/$ sales. Raising the average level of efficiency of the industry to that level would represent an improvement of just under 50% compared with the current average.

4.2.3 Decorative Chromium Plating

4.2.3.1 Wastewater

The rate of wastewater generation reported by companies in the database, at 2.27 gal/$ sales, was second only to zinc plating on a gallons per dollar of sales basis.

Table 4-8 lists the 30 companies in our database that reported carrying out decorative chromium operations. Performance in the top quartile would require a wastewater discharge rate of no more than 0.6 gal/$ sales. If the industry reaches that target level as an average, its performance would improve by 74% over the current level.

4.2.3.2 Sludge Generation

The industry average sludge generation rate from decorative chromium plating is 0.0082 lb/$ sales generated by that process.

Table 4-9 lists the 30 companies in the database for which we have sludge generation rate data. To perform as well as a company in the top quartile would require a rate no greater than 0.0024 lb/$ sales. To bring the industry average down to this level would represent a 71% improvement over current levels.

Table 4-8. Wastewater Discharge From Decorative Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %
16	0.00	100.0	54	0.64	40.0	55	2.25	8.0	52	3.80	33.0
13	0.00	21.0	41	0.70	90.0	75	2.43	60.0	138	3.82	30.0
119	0.24	50.0	121	0.80	25.0	56	2.83	10.0	74	3.87	38.0
4	0.35	77.6	47	1.13	12.0	6	3.04	100.0	71	4.50	54.0
149	0.42	10.0	24	1.19	100.0	44	3.15	42.0	46	4.98	7.0
117	0.60	45.0	82	1.31	90.0	140	3.33	3.0	14	5.50	40.0
134	0.61	11.0	43	2.13	4.0	67	3.62	10.0	141	5.60	20.0
			av	**2.27**		132	3.70	38.3	78	9.21	20.0

Table 4-9. Sludge Generation From Decorative Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %
4	0.0000	77.6	13	0.0025	21.0	41	0.0077	90.0	140	0.0131	3.0
43	0.0000	4.0	82	0.0030	90.0	52	0.0081	33.0	14	0.0131	40.0
55	0.0002	8.0	138	0.0033	30.0	**av**	**0.0082**		16	0.0135	100.0
141	0.0018	20.0	75	0.0036	60.0	47	0.0087	12.0	67	0.0152	10.0
46	0.0019	7.0	134	0.0037	11.0	6	0.0088	100.0	44	0.0242	42.0
119	0.0022	50.0	56	0.0039	10.0	71	0.0089	54.0	132	0.0259	38.3
149	0.0023	10.0	117	0.0040	45.0	24	0.0115	100.0	78	0.0421	20.0
54	0.0024	40.0	121	0.0046	25.0	74	0.0117	38.0			

4.2.3.3 Electricity Use

On average, companies in our database require 0.458 kWh/$ sales generated by decorative chromium plating.

We have data on electricity use from 30 companies that carry out decorative chromium plating operations, as shown in Table 4-10. Companies in the top quartile were able to generate each dollar of sales using no more than 0.229 kWh. Raising the average efficiency of the industry to that level would result in an improvement of 50% over current performance.

4.2.4 Electroless Nickel Plating

4.2.4.1 Wastewater

The industry average wastewater discharge rate for electroless nickel, according to the regression analysis of Chapter 1, was 1.42 gal/$ sales.

In Table 4-11, we have listed 33 companies that reported doing at least some electroless nickel plating. To be in the top quartile, a company could release no more than 0.3 gal of wastewater per dollar of sales attributed to the electroless nickel process. If the average of the industry were brought to that level, it would represent a 79% increase over the present performance.

4.2.4.2 Sludge Generation

The industry average sludge generation rate from electroless nickel plating is 0.0047 lb for each dollar of sales due to that operation.

Table 4-12 lists data from 31 companies on sludge generation rate from electroless nickel operations. Improving the industry average to the level achieved by companies in the top quartile, with 0.0007 lb/$ sales or less, would represent an improvement of 85% over current rates.

Table 4-10. Electricity Usage Rate for Decorative Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %
119	0.000	50.0	134	0.297	11.0	67	0.418	10.0	132	0.649	38.3
54	0.000	40.0	52	0.314	33.0	82	0.435	90.0	55	0.663	8.0
41	0.107	90.0	24	0.318	100.0	4	0.456	77.6	140	0.678	3.0
117	0.177	45.0	149	0.343	10.0	**av**	**0.458**		74	0.726	38.0
121	0.178	25.0	71	0.348	54.0	78	0.572	20.0	14	0.758	40.0
13	0.205	21.0	75	0.404	60.0	43	0.573	4.0	47	0.777	12.0
16	0.229	100.0	56	0.413	10.0	138	0.583	30.0	6	1.188	100.0
			44	0.415	42.0	46	0.604	7.0	141	1.302	20.0

Table 4-11. Wastewater Discharge From Electroless Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %
49	0.00	65.0	146	0.31	31.0	47	0.71	4.0	140	2.09	5.4
17	0.05	10.0	83	0.33	5.0	136	0.76	60.0	20	2.24	10.0
4	0.22	4.6	113	0.42	3.7	58	0.84	27.0	39	2.96	10.0
95	0.26	14.0	88	0.46	40.0	104	1.33	35.0	46	3.12	8.0
149	0.26	10.0	148	0.50	20.0	55	1.41	40.0	32	3.36	68.0
147	0.28	5.0	53	0.62	15.0	**av**	**1.42**		141	3.50	15.0
107	0.29	5.0	116	0.67	100.0	124	1.61	80.0	100	3.84	30.0
21	0.31	26.0	51	0.69	5.0	144	1.65	50.0	34	5.55	19.0
			66	0.69	5.0	44	1.97	15.0			

Table 4-12. Sludge Generation From Electroless Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %
32	0.0000	68.0	141	0.0008	15.0	124	0.0031	80.0	146	0.0049	31.0
58	0.0000	27.0	46	0.0008	8.0	100	0.0033	30.0	21	0.0052	26.0
17	0.0000	10.0	136	0.0008	60.0	20	0.0038	10.0	95	0.0054	14.0
4	0.0000	4.6	148	0.0009	20.0	47	0.0038	4.0	140	0.0057	5.4
55	0.0001	40.0	113	0.0009	3.7	83	0.0041	5.0	51	0.0071	5.0
88	0.0002	40.0	149	0.0010	10.0	**av**	**0.0047**		44	0.0106	15.0
66	0.0004	5.0	116	0.0024	100.0	107	0.0047	5.0	39	0.0138	10.0
53	0.0007	15.0	144	0.0030	50.0	147	0.0047	5.0	104	0.0178	35.0

That this dramatic increase is possible is indicated by the five companies who reported generating virtually no sludge (less than 0.1 lb/$1,000 in sales) from their electroless nickel operations.

4.2.4.3 Electricity Use

The electricity attributed to electroless nickel processing is consumed in auxiliary operations. Since the plating operation itself does not directly consume electricity, the overall average of 0.153 kWh/$ sales falls below that of electroplating processes.

Table 4-13 lists the 33 companies that provided data on electricity consumption attributable to electroless nickel operations. Companies in the top quartile consumed less the 0.070 kWh/ $ sales. If the industry average were raised to that level of efficiency, current usage rates for this process would have improved by 54%.

4.2.5 Anodizing

4.2.5.1 Wastewater

The industry average for wastewater discharge from anodizing operations is 1.96 gal/$ sales. The performance of the 28 companies in the data base carrying out anodizing operations is listed in Table 4-14. Entry into the top quartile of companies would require a wastewater discharge rate of no greater than 0.6 gal/ $ sales. Bringing the industry average to this level would represent an improvement of nearly 70% over the current rate.

4.2.5.2 Sludge Generation

The industry average value for the rate of sludge generation from anodizing processes, as estimated from the regression analysis, is given in Table 1-10 as “-0.01548” lb/$ sales. This is, of course, an impossible result. Several factors

Table 4-13. Electricity Usage Rate for Electroless Nickel Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %
34	0.000	19.0	58	0.108	27.0	44	0.181	15.0	46	0.263	8.0
20	0.000	10.0	113	0.112	3.7	104	0.181	35.0	55	0.288	40.0
51	0.000	5.0	39	0.113	10.0	4	0.198	4.6	140	0.295	5.4
66	0.000	5.0	49	0.119	65.0	53	0.200	15.0	47	0.338	4.0
83	0.000	5.0	21	0.126	26.0	147	0.210	5.0	95	0.344	14.0
124	0.016	80.0	144	0.134	50.0	100	0.212	30.0	136	0.403	60.0
88	0.063	40.0	146	0.147	31.0	107	0.233	5.0	116	0.429	100.0
32	0.070	68.0	149	0.149	10.0	148	0.233	20.0	141	0.566	15.0
			av	**0.153**		17	0.245	10.0			

Table 4-14. Wastewater Discharge From Anodizing

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %
70	0.00	60.0	118	0.68	16.0	99	1.69	70.0	122	3.05	40.0
49	0.00	6.0	53	0.86	17.0	104	1.83	19.0	132	3.20	10.0
90	0.25	11.1	92	1.04	90.0	**av**	**1.96**		138	3.30	15.0
149	0.37	30.0	135	1.06	23.1	93	1.99	14.0	46	4.30	21.0
107	0.40	15.0	58	1.15	45.0	62	2.01	28.0	141	4.84	10.0
40	0.43	100.0	61	1.22	80.0	42	2.05	92.0	100	5.30	65.0
88	0.63	40.0	87	1.67	27.0	72	2.13	23.0	34	7.66	32.0
						140	2.88	3.0			

combine to render the statistics meaningless for this case: we have relatively few companies that do any anodizing at all; for several of those whose process mix contains a large proportion of anodizing, we have incomplete data; and several companies with a large proportion of anodizing report generating zero sludge.

Table 4-15 includes the regression results for completeness, but the numbers are provided only for comparison purposes. It is probably fair to conclude that a reasonable target benchmark sludge generation rate for anodizing is zero.

Table 4-15. Sludge Generation From Anodizing

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %
87	-0.0198	27.0	107	-0.0051	15.0	149	-0.0011	30.0	62	-0.0001	28.0
104	-0.0193	19.0	72	-0.0047	23.0	46	-0.0009	21.0	92	0.0000	90.0
av	**-0.01548**		100	-0.0036	65.0	70	-0.0009	60.0	61	0.0000	80.0
132	-0.0123	10.0	122	-0.0022	40.0	141	-0.0008	10.0	58	0.0000	45.0
93	-0.0083	14.0	90	-0.0021	11.1	53	-0.0008	17.0	42	0.0061	92.0
140	-0.0062	3.0	135	-0.0017	23.1	88	-0.0002	40.0	40	0.0073	100.0
			138	-0.0016	15.0				99	0.0708	70.0

4.2.5.3 Electricity Use

On average, anodizing consumes 0.485 kWh/ $ sales. The 28 companies carrying out anodizing operations for which we have electricity usage rates are tabulated in Table 4-16. To perform in the top quartile, a company would have to use no more than 0.288 kWh/$ sales from anodizing operations. This corresponds to an improvement of 41%.

4.2.6 Hard Chromium Plating

4.2.6.1 Wastewater

The industry average for hard chromium plating was calculated to be 0.2 gal/$ sales on the basis of the regression analysis of Chapter 1.

In this case, as shown in table 4-17, enough companies have achieved a zero discharge rate (closed-loop operation) that achieving the level of performance of the top quartile means running a zero discharge operation. Enough companies have attained this level that we believe it to be a realistic benchmark target for all companies running hard chromium plating operations.

4.2.6.2 Sludge Generation

The industry average rate of sludge generation from hard chromium operations is 0.0060 lb/ $ sales. The 26 companies from whom we received sludge data on hard chromium operations are listed in Table 4-18. (As in other cases, the large number of zero values cause the median level to differ from the average.)

To perform in the top quartile would require generating virtually no sludge (less than 0.1 lb/ $1,000 in sales) from hard chromium operations.

Table 4-16. Electricity Usage Rate for Anodizing

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %
70	0.000	60.0	99	0.289	70.0	100	0.512	65.0	87	0.670	27.0
34	0.000	32.0	149	0.361	30.0	90	0.529	11.1	132	0.683	10.0
88	0.154	40.0	104	0.439	19.0	107	0.565	15.0	140	0.713	3.0
92	0.219	90.0	72	0.453	23.0	40	0.568	100.0	93	0.859	14.0
61	0.225	80.0	53	0.484	17.0	62	0.571	28.0	42	0.935	92.0
58	0.262	45.0	**av**	**0.485**		138	0.614	15.0	135	1.070	23.1
49	0.288	6.0	118	0.497	16.0	46	0.636	21.0	141	1.371	10.0
			122	0.497	40.0						

Table 4-17. Wastewater Discharge From Hard Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %	ID	gal/$ sales	Share of Sales, %
5	0.00	100.0	49	0.00	10.0	137	0.09	100.0	**av**	**0.20**	
19	0.00	100.0	123	0.00	56.8	48	0.09	20.0	75	0.21	39.0
25	0.00	100.0	17	0.01	90.0	66	0.10	57.0	124	0.23	20.0
30	0.00	100.0	95	0.04	86.0	135	0.11	14.0	132	0.33	16.7
97	0.00	100.0	83	0.05	95.0	68	0.11	99.0	46	0.44	3.0
129	0.00	100.0	54	0.06	5.0	82	0.12	10.0	141	0.49	10.0
89	0.00	95.0	148	0.07	20.0	55	0.20	35.0	78	0.81	70.0
									3	0.94	100.0

Table 4-18. Sludge Generation From Hard Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %	ID	lb/$ sales	Share of Sales, %
5	0.0000	100.0	55	0.0001	35.0	46	0.0016	3.0	124	0.0057	20.0
19	0.0000	100.0	129	0.0003	100.0	148	0.0016	20.0	**av**	**0.0060**	
25	0.0000	100.0	97	0.0004	100.0	54	0.0020	5.0	83	0.0077	95.0
30	0.0000	100.0	137	0.0005	100.0	82	0.0024	10.0	95	0.0101	86.0
89	0.0000	95.0	66	0.0008	57.0	135	0.0029	14.0	68	0.0110	99.0
17	0.0000	90.0	48	0.0009	20.0	75	0.0029	39.0	132	0.0212	16.7
123	0.0000	56.8	141	0.0015	10.0				78	0.0345	70.0

4.2.6.3 Electricity Use

Hard chromium plating is the most electricity-intensive of the six processes examined in this chapter, consuming an average of 0.536 kWh/ $ sales.

We have data from 25 companies, listed in Table 4-19. The top quartile has attained a level of efficiency considerably better than that of the average, as 0.284 kWh/$ sales or less. If the industry as a whole reaches that level, efficiency will have improved by 47%.

Table 4-19. Electricity Usage Rate for Hard Chromium Plating

1st Quartile			2nd Quartile			3rd Quartile			4th Quartile		
ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %	ID	kWh/$ sales	Share of Sales, %
124	0.037	20.0	75	0.420	39.0	129	0.524	100.0	132	0.674	16.7
48	0.185	20.0	5	0.420	100.0	68	0.529	99.0	55	0.690	35.0
89	0.221	95.0	30	0.435	100.0	**av**	**0.536**		19	0.714	100.0
137	0.260	100.0	82	0.453	10.0	148	0.558	20.0	95	0.823	86.0
97	0.276	100.0	123	0.467	56.8	17	0.587	90.0	135	1.057	14.0
49	0.284	10.0	25	0.515	100.0	78	0.594	70.0	3	1.140	100.0
						46	0.628	3.0	141	1.354	10.0

4.3 Summary

The target benchmark levels for wastewater disposal, sludge disposal, and electricity use, compared with current industry average performance levels, are summarized in Tables 4-20 through 4-22. The tables also indicate the amount of improvement that would result if average industry performance were raised to the benchmark level.

In each of the six processes considered here, we have enough companies already performing at these target levels to indicate that they are realistic and achievable for many metal finishers.

We have shown in Chapter 2 that the companies that have already improved their performance are ultimately saving money. Chapter 3 lists many of the pollution prevention practices that companies have implemented to achieve these savings. In this roadmap, we have shown where we currently stand as an industry and where we can go.

Let's go there.

Table 4-20. Summary of Benchmark Targets for Wastewater Disposal Rate

Process	Current Industry Average, gal/$ sales	Target Benchmark Level, gal/$ sales	Improvement Over Current Average, %
Zinc Plating	4.79	**2.5**	48
Nickel Plating	1.99	**0.5**	75
Decorative Chromium Plating	2.27	**0.6**	74
Electroless Nickel Plating	1.42	**0.3**	79
Anodizing	1.96	**0.6**	70
Hard Chromium Plating	0.2	**0.0**	—

Table 4-21. Summary of Benchmark Targets for Sludge Disposal Rate

Process	Current Industry Average, lb/$ sales	Target Benchmark Level, lb/$ sales	Improvement Over Current Average, %
Zinc (barrel) Plating	0.0540	**0.0166**	69
Zinc (rack) Plating	0.0164	**0.0075**	54
Nickel Plating	0.0066	**0.0018**	73
Decorative Chromium Plating	0.0082	**0.0024**	71
Electroless Nickel Plating	0.0047	**0.0007**	85
Anodizing	(-0.01548)	**0**	—
Hard Chromium Plating	0.0060	**0**	—

Table 4-22. Summary of Benchmark Targets for Electricity Use

Process	Current Industry Average, kWh/$ sales	Target Benchmark Level, kWh/$ sales	Improvement Over Current Average, %
Zinc Plating	0.510	**0.320**	37
Nickel Plating	0.453	**0.228**	50
Decorative Chromium Plating	0.458	**0.229**	50
Electroless Nickel Plating	0.153	**0.070**	54
Anodizing	0.485	**0.288**	41
Hard Chromium Plating	0.536	**0.284**	47

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