EPRI

A Marketing Guide for

Metal Finishing

A Marketing Guide *for* Metal Finishing

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Metal Finishing

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Report Summary

Small-business strategy is among the important issues energy suppliers are considering as deregulation approaches. Businesses engaged in metal finishing constitute a priority customer segment for many utilities. Success in retaining these customers, by delivering valued services, demands in-depth knowledge of their business issues and assistance needs.

BACKGROUND

Metal finishing is an integral step in the production of nearly all manufactured or fabricated products and is performed nationwide, both within manufacturing plants and by independent job shops. Industry experts agree that for lack of informed assistance, many metal finishing firms have not implemented changes in equipment and processes that would enhance their productivity, competitiveness, and/or environmental compliance. Providing assistance that supports metal finishers' transition to improved finishing practices and advanced electrotechnologies is a role energy suppliers can play.

OBJECTIVES

- To summarize current business data and industry trends and identify the issues of most concern.
- To describe the basic metal finishing processes and the commonly used and new technologies.
- To provide a method for targeting assistance to the most viable, needy, and receptive firms.
- To identify improvement opportunities and the types of assistance needed to promote change.

APPROACH

The project team researched the current-day trends and concerns of the metal finishing industry; the prevalent processes and the common and emerging technologies; and the industry's potential need for assistance in meeting business challenges. The resources tapped for the study included face-to-face and telephone surveys of industry members; reports published by state, regional, and federal agencies; industry journals and Web sites; trade organizations; and industry consultants.

RESULTS

The first chapter of the 137-page guide provides the latest data on industry size and sales, including descriptions of typical shop costs and business operations; reviews the continuing role of environmental regulation

in driving industry change; and outlines some significant business trends. Chapter 2 compiles information on metal finishing processes and technologies. Chapter 3 presents a strategy for collecting information, screening businesses, and targeting assistance to metal finishers via a three-level analysis of business viability and readiness for change. Utility readiness requirements for launching programs, and service offerings specific to metal finishing, are also described. Three case study examples show how to apply the targeting methodology and how to identify and address process improvement opportunities. Five appendices provide additional information: profiles of key technologies, names of equipment suppliers, names of trade associations, resources available in print and on-line, and a glossary of metal finishing terms.

INTEREST CATEGORIES

- Building systems and analysis tools
- Appliances

EPRI PERSPECTIVE

Effective marketing to the small-business sector demands that utilities understand the best products and services to offer each distinct business type. In January 1997, the Small-Business Solutions Target published *A Small-Business Guide: Metal Finishing,* which focused on delineating the role(s) and benefits of electric technologies in meeting the end-use needs of metal finishing firms. The current guide describes a segment-specific set of product and service offerings to facilitate utility marketing planning and foster success in strengthening relationships with metal finishing customers.

KEY WORDS

- Electrotechnologies
- Market research
- Marketing
- Metal coating processes
- Small-business customers

Abstract

Metals fabricating and metals-using manufacturing plants make up a large portion of the commercial/industrial business base in most utilities' trade areas. Metal finishing operations are a significant activity for many of these companies, and an activity that EPRI believes can benefit greatly from improved processes and practices, including the application of advanced electrotechnologies. Energy suppliers can play an important role in assisting metal finishing companies with identifying and applying business improvements. For these reasons, this market segment is very attractive to utilities that are looking to retain customers, capture new customers, and grow energy sales in an increasingly competitive market.

A Marketing Guide for Metal Finishing presents information for understanding the needs of companies performing metal finishing work, both their finishing process needs and general business practice needs. On the basis of this assessment, it provides utility marketing and sales personnel a methodology for ensuring outreach activities are targeted to the best candidate businesses, and identifies the types of assistance most needed by metal finishers.

Acknowledgments

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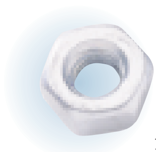
Business Trends



Metal finishing is an integral step in the production of nearly all manufactured or fabricated products—from everyday hardware such as bolts to decorative products such as jewelry, and from architectural elements such as sconces to heavy equipment such as crop harvesters. Collectively, the processes referred to under the umbrella of "metal finishing" contribute a variety of physical, chemical, engineering, and/or appearance qualities to the products to which they are applied.

Metals fabricating and metals-using manufacturing plants make up a large portion of the commercial/industrial business base in most utilities' trade areas. Metal finishing operations are a significant activity for many of these companies, and an activity that EPRI believes can benefit greatly from improved processes and practices, including the application of advanced electrotechnologies. Industry experts agree that, for lack of informed assistance, many metal finishing firms have not implemented changes in equipment and operations that would enhance their productivity, competitiveness, and/or environmental compliance. This is a role an energy supplier can play. For these reasons, this market segment is very attractive to utilities that are looking to retain customers, capture new customers, and grow energy sales in an increasingly competitive market.

A Marketing Guide for Metal Finishing presents information for understanding the needs of companies performing metal finishing work, both their finishing process needs and general business practice needs. On the basis of this assessment, it provides utility marketing and sales personnel a methodology for ensuring outreach activities are targeted to the best candidate businesses, and identifies the types of assistance most needed by metal finishers.

BRIEF OVERVIEW OF INDUSTRY

Metal finishing and manufacturing have a symbiotic relationship: the demand for metal finishing depends on the demand for products made of metal. In the present economic boom years of the 1990s, metal finishers are enjoying a period of high work volume and are anticipating continuing increases in business. While a decade ago, meeting environmental regulations was a top priority, today product quality, price, and turnaround time are the key business challenges. To maintain rapport with current customers and to gain new ones, metal finishers must match customers' requirements for quality and speed and offer competitive prices. The environmental regulations that rocked the industry in the late 1980s largely have been assimilated, but the regulatory arena is viewed as volatile because decision making occurs at all levels of goverment—federal to local. New federal regulations are expected in 2002, and the industry is watching these developments closely.

Currently, customer needs are driving change in the metal finishing industry. Retailers of metal products exert demands on product manufacturers, and manufacturers make demands on metal finishers—whether finishing is done within a manufacturing company or by an external supplier. Quick production, quality finishes, and low price are the focus of these demands, making productivity and competitiveness the current industry watchwords. These are the goals all metal finishers are talking about and striving to achieve. Modifications in shop practices and processes—a change in chemical mix or bath configuration—can significantly enhance turnaround and/or trim costs, thereby improving productivity. Advances in technology and in the understanding of metallurgy and chemistry are broadening the array of high-quality finishes possible, thereby allowing a company to compete in a new market. Energy suppliers can support the implementation of changes that foster the health and growth of the metal finishing businesses they serve.

The Importance of Finishing. Finishing is essential to the longevity of parts and products made from metal. By altering the surface of a metal product, finishing provides resistance to corrosion, wear, tarnish, chemical assault, and electrical current; enhances reflectivity, appearance, solderability, and electrical conductivity; and enables other special properties, such as bonding to rubber.

Metal parts and products typically undergo one or more physical, chemical, or electromechanical processes as part of their overall "finishing." Physical processes include buffing, grinding, polishing, and blasting. Chemical processes include cleaning, pickling, etching, polishing, painting/powder coating, and electroless plating. Electrochemical processes include plating, electropolishing, and anodizing. Embracing the vernacular of the marketplace, this guide categorizes the multiplicity of finishing operations into two basic categories: painting/coating and electroplating.

Captive versus Job Shops. Most metal finishing work is performed within a manufacturing plant, as a "captive" operation of the plant. According to a study by the U.S. Office of Technology Assessment, firms with captive operations comprise 85–90% of all companies that do some form of metal finishing. The remaining metal finishing businesses are relatively small entities, "job shops," that perform on contract for a manufacturer and are typically located near the manufacturer's facility. Most job shop businesses have just one facility and perform a relatively limited number of processes and/or work with primarily one type of manufacturing industry. Although closely linked to all types of manufacturing, the metal finishing business is in essence a service industry.

For both captive and job shop operations, the manufacturing industries served most frequently are

- machinery/industrial—producing engines, construction equipment, manufacturing equipment;
- automotive/original equipment manufacturers—producing automobiles, trucks, rail vehicles, boats; and
- computers/electronics—producing computers, audio and visual equipment, other office equipment.

Captive shops are also common among manufacturers for the defense/government industrial complex. Job shops perform a large volume of work for the hardware/tools industry. Other industries utilizing metal finishing services in high volume include automotive/truck aftermarket; building/construction; civilian aircraft; appliances; furniture/fixtures; jewelry; wire goods/pipe; sporting goods/toys; and medical.

Industry Segmentation. In the nomenclature of the federal Standard Industrial Classification (SIC) codes, six major industry groups are involved in metal working and therefore may conduct captive metal finishing operations:

- SIC 34: Fabricated Metal Products
- SIC 35: Industrial Machinery and Equipment
- SIC 36: Electronics and Other Electrical Equipment
- SIC 37: Transportation Equipment
- SIC 38: Instruments and Related Products
- SIC 39: Miscellaneous Manufacturing Industries

Shops that perform metal finishing as their primary business—job shops—are classified within SIC 34. They are categorized as Electroplating, Plating, Polishing, Anodizing, and Coloring (SIC 3471); and Coating, Engraving, and Allied Services (SIC 3479). The definitions of these SIC categories are given in table 1. Note that in many discussions, this guide focuses on data collected specifically for SIC codes 3471 and 3479 because these data are sure to describe conditions or operations relevant to metal finishing rather than to a parent manufacturing group.

Historically, utilities have used SIC codes for segmenting commercial and industrial customers. However, this method of segmentation has proved of limited usefulness in locating metal finishers among all businesses categorized in SICs 34–39.

Moreover, the familiar SIC system, used since the 1930s for segmenting industry, is soon to change. In April 1997, a new industry classification system was announced, a change driven by the North American Free Trade Agreement (NAFTA). The intention is

TABLE 1. Metal Finishing Processes Identified by SIC Code

SIC Category	Definition
3471 Electroplating, Plating, Polishing, Anodizing, and Coloring	Establishments primarily engaged in all types of electroplating, plating, anodizing, coloring, and finishing of metals and formed products for the trade. Also included in this industry are establishments which perform these types of activities, on their own account, on purchased metals or formed products. Establishments that both manufacture and finish products are classified according to the products.
3479 Coating, Engraving, and Allied Services, Not Elsewhere Classified	Establishments primarily engaged in performing the following types of services on metals, for the trade: 1) enameling, lacquering, and varnishing metal products; 2) hot dip galvanizing of mill sheets, plates and bars, castings, and formed products fabricated of iron and steel; hot dip coating such items with aluminum, lead, or zinc; retinning cans and utensils; 3) engraving, chasing and etching jewelry, silverware, notarial and other seals, and other metal products for purposes other than printing; and 4) other metal services, not elsewhere classified. Also included in this industry are establishments which perform these types of activities on their own account on purchased metals or formed products. Establishments that both manufacture and finish products are classified according to the products.

TABLE 2. New North American Industry Classification System

SIC	Description	NAICS	Description
3471	Electroplating, Plating, Polishing, Anodizing, and Coloring	332813	Electroplating, Plating, Polishing, Anodizing, and Coloring
3479	Coating, Engraving, and Allied Services, Not Elsewhere Classified	339914	Costume Jewelry and Novelty Manufacturing
		339911	Jewelry (except Costume) Manufacturing
		339912	Silverware and Plated Ware Manufacturing
		332812	Metal Coating, Engraving (except Jewelry and Silverware), and Allied Services to Manufacturers

to facilitate more accurate comparison of economic and financial statistics among the partner countries. The new system—the North American Industry Classification System (NAICS)—will replace the separate classification schemes now used by the United States, Mexico, and Canada with one uniform system. Table 2 compares the old and new schemes for SICs 3471 and 3479.

Industry Size. Because there are both job shops and captive operations, and multiple metal-working SICs, it is difficult to accurately estimate the number of establishments in the United States engaged in metal finishing. Estimates from industry surveys conducted by trade groups and by EPRI are that 25–55% of metal working companies in SICs 34–39 have captive shops that perform metal finishing. Urban versus rural sampling in these surveys may explain the range: in rural settings, more metal working companies do finishing on site (i.e., have captive shops), resulting in the 55% figure. However, the majority of manufacturing and metal finishing work is performed in urban settings,

TABLE 3. Size of the Metal Finishing Industry

Category	No. of Companies	No. of Employees	Sales per Employee, $	GDP Contribution, $ billions
Captive shops	4,700	220,000	76,000	17
Job shops	4,300	210,000	75,000	16
Circuit board shops	700	70,000	100,000	7
Total Finishers	**9,700**	**500,000**	–	**40**
Materials	400	18,000	400,000	7
Equipment	100	2,000	350,000	1
Total Suppliers	**500**	**20,000**	–	**8**
Grand Total	**10,200**	**520,000**	–	**48**

Source: Surface Finishing Market Research Board, *Metal Finishing Industry Market Survey, 1996–97*.

TABLE 4. Profile of the Metal Manufacturing and Finishing Industry (1995)

Category	No. of Companies	No. of Employees	Sales per Employee, $	GDP Contribution, $ billions
Captive shops	4,700	220,000	76,000	17
Job shops	4,300	210,000	75,000	16
Circuit board shops	700	70,000	100,000	7
Total Finishers	**9,700**	**500,000**	–	**40**
Materials	400	18,000	400,000	7
Equipment	100	2,000	350,000	1
Total Suppliers	**500**	**20,000**	–	**8**
Grand Total	**10,200**	**520,000**	–	**48**

Source: U.S. Dept. of Commerce, *County Business Patterns—1995.*

where only 25% of manufacturers are estimated to have captive operations.

The Surface Finishing Market Research Board (SFMRB), an industry group, reports the industry's current size as 4700 captive shops, 4300 job shops, 700 printed circuit board shops, and 500 suppliers, for a total of 10,200 companies nationwide (see table 3). These data are based on a survey conducted in 1996–97 by SFMRB; the results provide information on captive and job shop revenues and expenditures from about 500 respondents across the country. U.S. census data, shown in table 4, indicate there are 149,381 establishments in all metal working-related SICs (including SICs 3471 and 3479). Based on these data, job shops (SICs 3471 and 3479) make up 4% of the total number of establishments engaged in all types of metal working. Likewise, using these data and assuming 25% of all the businesses have captive metal finishing operations yields an estimate of roughly 36,000 captive shops in the United States.

The U.S. Department of Commerce reports that revenues for SICs 3471 and 3479 were about $9.66 billion in 1992. Based on a total of 5343 establishments in these two SICs, the average revenue per establishment is about $1.8 million dollars.

According to data collected by SFMRB in its 1996 survey, metal finishing job shops and captive operations generate about $48 billion in revenue annually. Eliminating costs for materials and equipment, the SFMRB estimates this is equivalent to an annual gross domestic product contribution of about $40 billion. Among captive shops participating in the survey, 57% reported 1996 revenues of less than $1 million, but 17% had revenues over $10 million. Among job shops, 30% reported 1996 revenues as less than $1 million and 34% reported revenues of $1–$3 million. Overall, these data, shown in table 5, suggest an average of about $75,000 in sales revenue per employee for all shops.

Comparing SFMRB's 1996 revenue data with data from a similar survey conducted in 1995 shows that nearly 60% of all finishers reported increased sales; less than 10% of captive shops and less than 20% of job shops reported a decline in sales. Most of the

TABLE 5. Sales Volume for Finishers (1996)

$ Millions	Captive Shops	Job Shops
< 0.5	36.6%	21.2%
0.5–1.0%	20.3%	9.2%
1.0–2.0	8.1%	18.4%
2.0–3.0	4.9%	15.2%
3.0–5.0	8.9%	9.2%
5.0–7.0	0.8%	6.0%
7.0–10.0	3.3%	11.4%
> 10.0	17.1%	4.9%

Source: Surface Finishing Market Research Board, *Metal Finishing Industry Market Survey, 1996–97.*

respondents also forecast a continuing increase in business: 50% of captive shops expected more work in 1997 and 66% of job shops believed they would see increased business. These forecasts, however, are slightly less optimistic than those reported in past SFMRB industry surveys.

TABLE 6. Number of Employees in Metal Finishing Shops

Range	Captive Shops	Job Shops
1–10	33.2%	25.4%
11–20	19.9%	12.7%
21–30	12.0%	16.4%
31–50	9.2%	18.0%
51–75	7.8%	7.4%
76–100	6.0%	6.9%
101–200	6.0%	10.6%
> 200	6.0%	2.6%
Median	19	28
Average	46	48

Source: Surface Finishing Market Research Board, *Metal Finishing Industry Market Survey, 1996–97.*

Shop Size. The metals finishing industry is dominated by small businesses. The SFMRB's survey data for captive and job shops, depicted in table 6, show that 33% of captive shops and 25% of job shops employ up to 10 people. The median is 19 employees in captive shops and 28 in job shops; the average is 46 employees in captive shops and 48 in job shops. (The median figure reflects the large concentration of shops with fewer than 10 employees.) Overall, according to SFMRB data, 74% of captive shops employ fewer than 50 people, and 73% of job shops employ fewer than 50 people.

The survey data also suggest that the shops themselves are small: about 40% of captive shops and 30% of job shops are 10,000 square feet; another 23% of captive shops and 27% of job shops are 10,000–20,000 square feet. The median size for both captive and job shops is 18,000–19,000 square feet. The average captive shop is about 27,000 square feet, and the average job shop is about 33,000 square feet.

Shop Business Operations. Many of these small shops are undercapitalized. An industry profile published in 1995 by the federal Technology Reinvestment Program (TRP) reports that gaining access to capital is difficult for many metal finishing firms. Capital investments today are largely driven by customer demand (for speed, quality, etc.) and therefore hinge on the economy and expected business conditions. According to the TRP, the average annual investment for metal finishing facilities is low: for plating facilities, it is 17% of the norm for all manufacturing establishments; for coating, it is 23%. These data, however, do not account for differences in relative business size. Another key indicator is investment per production worker: investments per worker in the metal finishing industry are 36% (plating shops) and 42% (painting shops) of the national manufacturing average, according to TRP.

These figures seem to jibe with SFMRB data on capital expenditures, which indicate that more than half of all finishing facilities spend less than $100,000 annually for capital equipment. The survey also gathered data on operating costs as a percentage of sales revenue. Nearly half the captive shops responding to questions on payroll reported that payroll is less than 20% of revenue; this may reflect a high degree of shop automation and exclusion of corporate salaries in their calculations. By contrast, the median payroll cost for job shops was 34%, likely because of less automation and inclusion of management salaries.

Other employee costs (benefits, training) average about 5% for all finishers as a percentage of sales revenues. The materials cost average is about 17.7% for captive shops and 19.3% for job shops. Maintenance costs (machinery, buildings, equipment) as a percentage of revenues have a median value of 4–5% for all finishers. The costs of utility services (gas, electric, etc.) are reported as averaging 5% for captive shops and 6% for job shops (see table 7). The lower cost for captive shops may simply denote a lack of awareness of process energy requirements. The costs of trucking and hauling were below 2% of revenues for 59% of captive shops and 55% of job shops.

The SFMRB survey also investigated capital expenditures for regulatory compliance; these data show that about 50% of captive shops and 40% of job shops spend less than $10,000 annually on compliance. Another 32% of captive shops and 30% of job shops spend $10,000–$50,000 annually. The number of employees committed to compliance work is about three in captive shops and job shops alike, but 20–30% of job shops report either no or just one employee assigned to compliance. These shops likely rely on outside consultants instead. The costs for waste treatment as a percentage of sales revenue are reported averaging close to 3% for both captive shops and job shops.

TABLE 7. Cost of Utility Services as a Percentage of Sales Revenue

Utility Services/Sales Revenue	Captive Shops	Job Shops
< 3%	23.2%	17.0%
3–4%	31.7%	22.0%
5–6%	25.3%	26.7%
7–10%	12.7%	23.3%
10–12%	2.1%	5.8%
> 12%	5.0%	5.2%

Source: Surface Finishing Market Research Board, *Metal Finishing Industry Market Survey, 1996-97.*

Energy Use. Energy utilization is largely driven by the type of processes performed at the metal finishing business. Small shops with manual process operations and a small labor force typically use less energy than shops with an automated process and a larger labor force. Electroplaters tend to use more energy for operating “rectifiers,” which convert and modify alternating current (ac) electricity to direct current (dc) for use in driving the electrodeposition process. Painters and coaters use more energy for drying. All metal finishers use substantial amounts of energy for heating of process solutions, motors, and process and ambient air.

Research conducted by Centerior Energy and Battelle (1993) gives some idea of typical load factors for a range of metal finishers. (A lower load factor indicates greater variability in demand over a given period of time.)

- Large automated rack plater, 45.4%
- Medium manual anodizer, 23.5%

- Small manual anodizer, 14.0%
- Small automated rack plater, 43.7%
- Large barrel plater, 54.0%
- Medium manual hard chrome plater, 62.3%
- Large automated rack plater, 62.2%
- Small manual rack plater, 29.5%
- Small integrated painter, 32.2%
- Large painter, flat stock, 30.0%
- Large painter, job shop automated, 44.4%

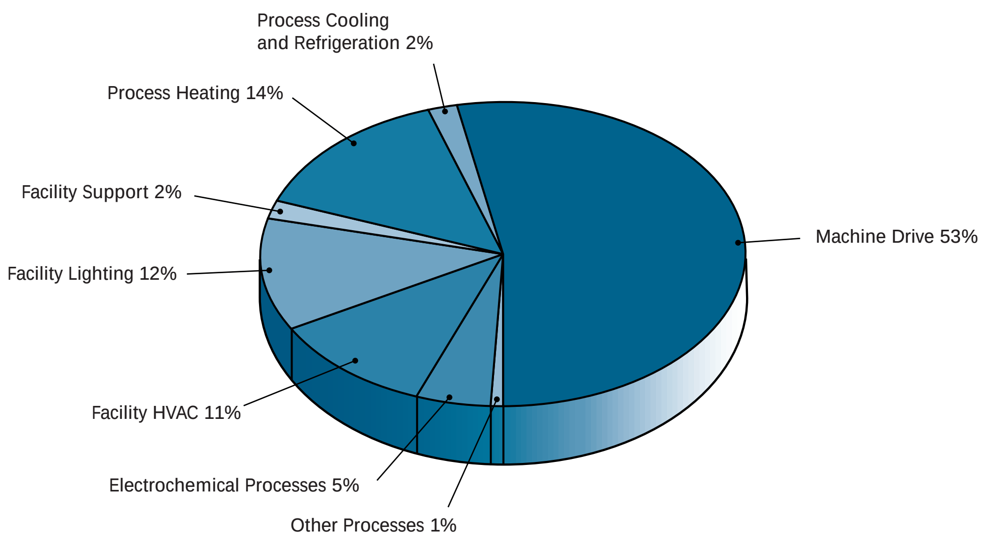
Figure 1 depicts electricity use at the typical fabricated metals product manufacturing plant (SIC 34) by end-use category. Machine drive and process heating are the two largest categories, together responsible for 67% of electricity use. Conventional facility support end uses (i.e., space conditioning, lighting, and office equipment) drive just 25% of the total electricity use.

The net demand for electricity in this industry was reported by the U.S. Energy Information Administration (1994) as 34,387 million kWh. U.S. Bureau of Census data from the *1996 Annual Survey of Manufactures* on the quantity of electric energy used for heat and power shows that SIC 3471 used 2301 million kWh, and SIC 3479 used 2304 million kWh, at a total purchase cost of $286.4 million.

Shop Location. Metal finishing businesses are located across the country—in city, suburban, and rural environments—but concentrate near manufacturing regions; that is, near their customers. Census data by state show California has twice as many businesses in SICs 3471 and 3479 than any other state. As depicted in figure 2, the Midwest and Northeast regions also have high numbers of shops.

The interrelatedness of manufacturing and metal finishing determines the regional differences in metal finishing operations. For example, shops that perform hard chrome plating are generally found in the Northeast and Midwest, near industrial machinery

FIGURE 1. Net Demand for Electricity by End Use (SIC 34)



Source: Energy Information Administration, Office of Energy Markets and End Use, Energy End Use and Integrated Statistics Division, 1994.

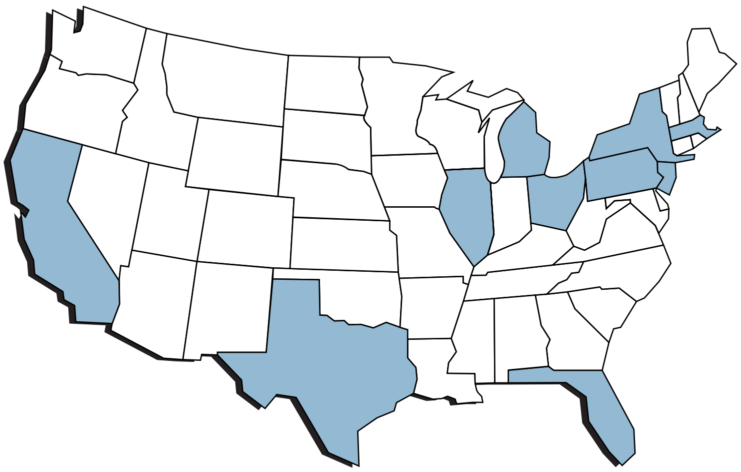


FIGURE 2. Top States for Metal Finishing and Metals-Related Manufacturing (SICs 34–39)

Number of Establishments	
CA	21,175
MI	8,793
TX	8,761
NY	8,743
OH	8,673
IL	8,552
PA	7,012
FL	5,960
NJ	4,974
MA	4,646

Source: U.S. Dept. of Commerce, *1992 Annual Survey of Manufactures.*

manufacturing centers. Another example is copper plating. In the eastern United States, copper plating is primarily used in industrial applications and often as a base for chrome plating. In the west, copper plating is primarily used in the electronics industry and the process itself is very different, requiring higher standards and stricter quality control.

POLLUTION CHALLENGE

Companies that perform metal finishing operations are subject to extensive environmental, safety, and health regulations; the industry is one of the most chemical-intensive and heavily regulated in the country. Many of the current regulations were promulgated in the 1980s and have been accommodated by the businesses still in operation. Even so, environmental regulations continue to play a decisive role in business practice and profitability.

The federal regulations reflect the hazardous nature of the work and the many chemicals involved in metal finishing processes (see table 8). The metallic compounds used in organic solvents and the electroplating processes are the primary materials triggering environmentally related regulations. Those of greatest concern are toxic metals (cadmium, copper, chromium, nickel, lead, and zinc); cyanide; toxic organics (typically grouped together and referred to as “total toxic organics”); and conventional pollutants (total suspended solids and oil and grease). The organic solvents emit volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) that contribute to ozone and smog. The other process constituents degrade water quality, endanger aquatic life and human health, corrode equipment, generate hazardous gases, and result in hazardous solid waste.

Metal finishers are regulated by the Clean Air Act and the 1990 Clean Air Act Amendments (CAAA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and Superfund. Metal finishers are also affected by Occupational Safety and Health Administration (OSHA) regulations. The EPA is responsible for preparing the pollution regulations and administering the federal laws that drive them. Because the laws for management of wastewater and solid

TABLE 8. Metal Processing and Finishing: Material Inputs and Wastes

Process	Material Input	Air Emission	Process Wastewater	Solid Waste
Metal Shaping				
Metal cutting and/or forming	Cutting oils, degreasing and cleaning solvents, acids, alkalis, and heavy metals	Solvent wastes (e.g., 1,1,1-trichloroethane, acetone, xylene, toluene, etc.)	Waste oils (e.g., ethylene glycol) and acid (e.g., hydrochloric, sulfuric, nitric), alkaline, and solvent wastes	Metal chips (e.g., scrap steel and aluminum), metal-bearing cutting fluid sludges, solvent wastes, and still bottoms
Surface Preparation				
Solvent degreasing and emulsion, alkaline, and acid cleaning	Solvents, emulsifying agents, alkalis, and acids	Solvents (associated with solvent degreasing and emulsion cleaning only)	Solvent, alkaline, and acid wastes	Ignitable wastes, solvent wastes, and still bottoms
Surface Finishing				
Anodizing	Acids	Metal ion-bearing mists and acid mists	Acid wastes	Spent solutions, wastewater treatment sludges, and base metals
Chemical conversion coating	Metal and acids	Metal ion-bearing mists and acid mists	Metal salts, acid, and base wastes	Metal and reactive wastes
Electroplating	Acid/alkaline solutions, heavy metal bearing solutions, and cyanide bearing solutions	Metal ion-bearing mists and acid mists	Acid/alkaline, cyanide, and metal wastes	Metal and reactive wastes
Plating	Metals (e.g., salts), complexing agents, and alkalis	Metal ion-bearing mists	Cyanide and metal wastes	Cyanide and metal wastes
Painting	Solvents and paints	Solvents	Solvent wastes	Still bottoms, sludges, paint solvents, and metals
Other metal finishing techniques (including polishing, hot dip coating, and etching)	Metals and acids	Metal fumes and acid fumes	Metal and acid wastes	Polishing sludges, hot dip tank dross, and etching sludges

Source: EPA Office of Compliance, Sector Notebook Project, *Profile of the Fabricated Metals Products Industry*, September 1995.

waste were passed at different times, the EPA has different schedules for their implementation. This puts a burden on metal finishers to stay abreast of new and changing regulations while aiming for a cost-effective, integrated approach to compliance.

Metal Finishing Wastes and Regulations. Metal finishers are responsible for disposal of their solid wastes, which are defined as including all substances not covered by the Clean Water Act or the Atomic Energy Act. In 1980, the EPA defined four properties that distinguish a waste as hazardous: ignitability (flash point of 140°F or lower), corrosivity (pH below 2 or above 12.5), reactivity (tendency to explode or react vigorously with air or water), and toxicity (releases materials in sufficient amounts to pose a substantial hazard to human health or to the environment). Certain other wastes are deemed hazardous unless proven otherwise: wastewater treatment sludges, spent plating bath solutions, sludges from the bottom of plating baths, and spent stripping and cleaning bath solutions.

Hazardous waste regulations also offer special provisions for "small quantity generators"(SQGs)—facilities that produce 200–2000 pounds of hazardous waste per month. Most metal finishers are SQGs; for hazardous wastes disposal, they are required to obtain an identification number from the EPA and to maintain a uniform manifest system when transporting sludge off-site for treatment and disposal. Typically, metal finishers store sludge in a drum on-site until it is hauled away by a third-party contracted to ensure proper treatment and disposal. A ban on land disposal of hazardous waste means that waste must be treated before deposit in a landfill; reducing the quantity of hazardous sludge minimizes these costs.

The vast majority of small metal finishing businesses discharge wastewater to publicly owned treatment works (POTWs). POTWs are primarily designed to treat domestic sewage. Many industrial wastes are compatible with the treatment system. Others, however, may pass through the POTW untreated or interfere with its normal operation, rendering the POTW in violation of its permit or unable to dispose of its sludge. To meet the requirements of the CWA, the EPA has developed technology-based standards for metal manufacturing and finishing businesses that discharge to a POTW. These "categorical" pretreatment standards are compiled in guidelines applicable on a nationwide basis. Individual POTWs may also develop "local limits" (typically more stringent than the EPA's) to help them achieve the effluent limitations of their National Pollutant Discharge Elimination System permits. Facilities discharging less than 10,000 gallons per day are subject to more lenient standards than larger facilities. Larger facilities have two alternatives for compliance: restrict the mass of pollutants discharged (resulting in a low but concentrated effluent volume), or restrict the concentration of pollutants.

New Regulations Under Development. The EPA is developing a set of new regulations applicable to all industries involved in "Metal Products and Machinery" (MP&M). The proposed regulations will be announced in October 2000. Final regulations are due in December 2002. The metal finishing industry is proceeding with business-as-usual while tracking development of the new MP&M regulations. Existing regulations are categorized by industry sector; this formulation is inherently confusing because the same processes are practiced in many industrial sectors and each industry was given different rules. By contrast, the MP&M regulations will set out regulations by process, such that the regulations for chromium plating, for example, will be applicable to all facilities performing the process.

The metal finishing industry is very concerned that the EPA accurately calculate the cost-benefits resulting from regulations. The U.S. Congress requires the EPA to consider the potential economic impact of regulations. Since many finishing shops operate at a narrow economic margin it is likely that any increase in regulatory pressure will force some out of business.

Even without the imposition of new regulations, metal finishing job shops that continue to operate without adhering to today's environmental regulations are in increasing jeopardy as enforcement activities step up. Most of the shops in this category are among the smallest in the industry. Lack of access to capital and a fundamental need for proof (preferably a demonstration or another user's testimony) that a new system will perform as described are the typical barriers in these shops to embracing new technology.

Most shops today, and certainly all those established since the late 1980s, are aware of the regulatory requirements pertaining to their processes and have systems in place to reduce water use, wastewater volume, and air emissions. Many organizations have formed to assist metal finishers in learning of, implementing, and improving pollution prevention technologies. Government-sponsored laboratories, university research programs, and state- and federally sponsored programs are developing technology and conducting technology transfer. The EPA's Common Sense Initiative program includes a metal finishing component that promotes new pollution prevention techniques through research, workshops, and collaborative projects with trade associations and industry. The metal finishing industry's three trade associations (see Resources, appendix D) are also active in building coalitions between industry and government to ensure metal finishers can achieve both compliance with pollution regulations and improved business performance and competitiveness. As a result of these efforts, technology transfer has played a pivotal role in the industry's changes over the last two decades. But many companies lack in-house resources to devote to studying and locating process and treatment equipment options. Frequently, the treatment systems in-place are those introduced by a trusted equipment or chemical vendor.

EPA Compliance Policy for Small Businesses. A federal regulatory reform initiative effective in June 1996 gave federal agencies the discretion to modify regulatory penalties for small businesses (defined as businesses with fewer than 100 employees). Specifically, the new policy stipulates that the EPA will "refrain from initiating an enforcement action seeking civil penalties, or will mitigate civil penalties, whenever a small business makes a good faith effort to comply with environmental requirements by receiving compliance assistance or promptly disclosing the findings of a voluntarily conducted environmental audit, subject to certain conditions. These conditions require that the violation is the small business's first violation of the particular requirement; does not involve criminal conduct; has not and is not causing a significant health, safety, or environmental threat or harm; and is remedied within the corrections period." The policy complements the federal mandate that states operate Small Business Assistance Programs (SBAPs) to provide technical and environmental compliance assistance to businesses that are stationary sources of pollution. It is intended to "promote environmental compliance among small businesses by providing incentives for them to participate in on-site compliance assistance programs and to conduct environmental audits."

EPA Enforcement Activities. The EPA's Office of Compliance notebook on SIC 34, *Profile of the Fabricated Metal Products Industry*, reports that among 17 key industry segments, the fabricated metal products industry "comprises the largest number of facilities tracked by EPA" and likewise has the largest number of inspection and enforcement actions. Over the five-year period reviewed, 1340 fabricated metal businesses were inspected, for a total of 5509 inspections. These inspections found 280 facilities requiring one or more enforcement actions, for a total of 840 actions (includes state and federal actions). This is an enforcement to inspection rate of 15%. Three industries had higher enforcement to inspection rates: electronics (27%), petroleum refining (25%), and organic chemicals (19%).

INDUSTRY TRENDS

Over the last decades, changes have occurred in the types of finishing performed and the finishing methods employed by metal finishers. For example, the advent of more benign processes such as powder coating has lessened demand for some of the more noxious traditional techniques, such as arsenic-based processes and chrome plating (which employs highly toxic hexavalent chromium). These older, relatively simple processes are now increasingly performed outside the United States, while more sophisticated, alternative processes are implemented here. Newer waste treatment technologies are also slowly integrating into the mainstream. During the 1980s, such technologies as ion exchange filtration and membrane filtration were rare and considered exotic. Today, many shops are aware of these technologies and a growing population of small- to medium-sized metal finishing shops are using them.

Shops today are also increasingly specialized in terms of both the finishes they perform and the types of parts they finish; this has functions in both productivity and competitiveness. For example, a shop might perform only hard chrome plating of rod stock for hydraulic pistons in heavy-lift equipment. Another shop might conduct only electroless nickel plating of aluminum for the electronics industry. Shops that specialize in this way can invest judiciously in equipment and training of line workers to maximize equipment usage and service quality, thus achieving good rates of productivity.

Among the domestic metal finishers enjoying the most lucrative success are those providing structural (vs. aesthetic) finishes; these jobs require strict adherence to engineering specifications but also provide for high profits. Similarly, the metal finishers with access to capital for unique equipment and who are willing to conduct extensive employee training are serving the high-ticket-item aerospace, electronics, and defense industries. These situations often demand very high-quality finishes on low-volume production lines that use expensive machinery and a small highly trained work force. These companies enjoy a significant competitive advantage.

As with all manufacturing industries, favored suppliers deliver a lower cost product on time and at the expected level of quality. Certain characteristics of the metal finishing industry, however, make price competition particularly aggressive:

- It is a buyers' market—Manufacturers can play firms off each other to obtain the best price; there's little to no "cost" to them for switching suppliers.
- Finishers are flexible—In some cases, relatively small investments in new equipment and chemistries can enable participation in a whole new market.
- Disincentive to quit—By one federal estimate, any metal finishing facility over 15–20 years old is likely to have some site contamination problem, so while market forces would ordinarily cause foundering firms to drop out, there are those that

would rather stay in business and lose money than face clean-up costs.

Low/High Value-Added. Recent industry data suggest that issues of price are becoming secondary to the "class" of metal finishing performed: low-value-added or high-value-added.

Industry sources believe that over half the metal finishing establishments in the United States are so called "low-value-added" firms. Low-value-added firms serve a variety of markets and finish relatively high volumes of simple parts that have simple geometries and routine specifications (e.g., hardware fasteners, decorative chrome, steel construction parts). These firms compete on price and productivity, each seeking to be the lowest-cost provider. Some of the firms serving as low-cost providers are capital-poor due to price competition; they use older processes because they cannot undertake the risk of investment in new technology. They are also susceptible to international competition. As more U.S. companies fabricate and assemble products outside of the country—to take advantage of cheaper labor—some metal finishing work goes overseas as well.

Currently, growth in the domestic metal finishing industry is largely taking place among the high-value-added finishers; this is a highly competitive arena nationally. These finishers typically work on expensive and/or intricate parts, use precious metals, and meet special performance and/or very exacting specification requirements. Product examples include aerospace and defense equipment, medical instruments, and electronic components. Rather than competing primarily on price, these firms offer superior performance to meet the increasingly rigorous specifications required by the high-tech industries. These shops often have closer relationships with their customers (they are "first-tier" suppliers with direct relationships), and there is less likelihood of international competition.

The environmental implications of these "classes" are not clear. Low-value-added firms are unlikely to have the time or resources to plan, purchase, and optimize pollution control equipment, especially given the potential need to quickly modify their process lines to fill an incoming order. And because they are typically second-, third-, or fourth-tier suppliers, they have little opportunity to enlist manufacturers in design or specification changes that would accommodate waste reduction practices in their shops. High-value-added firms are not only better funded and closer to their customers, they typically operate fewer processes, which greatly simplifies wastestream management. They are also better and equipped and positioned to implement environmental controls.

Environmental regulations are also exerting an influence on workforce requirements. Specifically, while the industry has historically depended on the know-how of experienced workers, the new compliance technologies demand formal worker education and training. In general, process operators and shop managers are adopting professionalism. In high-value-added shops especially, manufacturers consider formal training and ISO 9000 certification relevant criteria when selecting new suppliers.

In some cases, manufacturers are looking to reduce their number of suppliers but establish closer working relationships with those they retain as vendors—aiming to minimize costs and maximize quality. Manufacturers are concerned about developing close sourcing relationships with facilities that have environmental liabilities. Some screen a vendor's environmental management and compliance activities, sometimes working with the supplier to implement preferred alternatives. On the downside, becoming a preferred supplier does not eliminate price concerns: adding the costs of compliance technology to product price is known to have ended some contracts. This type of experience has made finishers highly cautious about implementing process change.

Outsourcing. Business, production, economic, and environmental factors determine whether finishing is done in a captive environment or contracted to a job shop. Metal finishing is often the last operation on a product before packaging or final assembly. It can require capital-intensive operations but have minor impact on the overall market value of the product. And it is chemical-intensive, generating waste streams that are often complex and expensive to treat. These factors promote outsourcing to job shops.

In some ways, captive finishing is synonymous with high-value-added production. According to an industry profile published by the federal TRP, captive operations dominate when proprietary technology is involved, quality assurance is critical, parts are unique or too large for easy transport, finishing must dovetail with other production line actions, or when finishing capacity has a high rate of utilization.

The traditional wisdom has been to outsource when these factors are not present, or when environmental regulations are too demanding. A new element driving outsourcing is the advent of cellular manufacturing (in which a complete manufacturing process takes place in multiple modules or at a number of separate facilities), flexible manufacturing systems, and corporate reexamination of cost structures.

Some large manufacturers, desiring to streamline their operations, are rejecting the status quo of taking up valuable floor space with finishing capacity that is used only 20–30% of the time. However, while many in the industry report having increased their outsourcing, only 2% of the firms surveyed by EPRI in 1998 planned to increase outsourcing.

Low estimates are given for outsourcing to companies out of the country, too (where labor rates might be lower). In Silicon Valley, at least, such outsourcing is currently out of the question. The hot market for information technologies and services means that platers in the area often have only 24 hours or less to finish products. Zinc-plated computer casings are one example: the pieces are manufacturered, plated, painted, and shipped to the computer assembly plant in mere days. A similar condition holds for electroless nickel plating of hard drive disks. There is simply no time to send parts out of the valley.

METAL FINISHING BUSINESS NEEDS

In 1998, EPRI surveyed metal finishers in job shops and captive operations in metals-related manufacturing companies in the Midwest to explore their business needs. Among other questions, respondents were asked to identify the factors most influencing change at their companies. Specifically, they were asked to rate the impact of four factors on their decision making: customer demands, existing competition, new competition, and EPA regulations. The ranking was done on a scale of 1 to 6, with 1 indicating no influence and 6 indicating significant influence.

All respondents reported that customer demands have the most important influence on their business decisions (see table 9). This seems in keeping with the industry's focus on producing quality work, on time,

TABLE 9. Key Factors Influencing Change

Industry Segment	Do Plating and Painting	Customer Demands	New Competition	Existing Competition	EPA Regulations
Electroplating					
Job shops (10)	40%	2.9	1.1	1.8	2.0
Captive shops (3)	67%	NA	NA	NA	NA
Painting/Coating					
Job shops (9)	11%	4.1	3.0	3.0	3.2
Captive shops (21)	15%	3.8	2.6	2.7	1.9

Source: EPRI 1998 Metal Working Study (with QDI Strategies, Inc.). Sample size of 55, including metal finishers and metals-related manufacturing companies; data in parenthesis is number of shops surveyed in each segment.

and at the price the customer can afford. It may also allude to what the industry experiences as increasing demand for customized finishes. (Note that responses were not available from the three captive shops identified with electroplating.)

For both electroplating job shops and coating/painting job shops, considerations related to EPA regulations were ranked second in importance. Perhaps these shops feel more exposed to potential EPA scrutiny. Likewise, they may have fewer resources—both personnel and financial—to devote to analyzing the regulations and their relevance to their operations, as well as to determining the most efficient or economic means for staying within regulatory guidelines. By contrast, captive shops performing coating and painting operations ranked EPA regulations as their last concern.

Instead, for captive painting/coating shops, existing competition and new competition ranked, respectively, second and third in importance. This may indicate that job shops are now given the most challenging jobs (potentially those requiring the most environmental hazards control) and that captive shops are concerned about potential downsizing. Comments from survey participants suggest this view, in that manufacturers with captive coating operations talked about sending their specialized jobs outside the company.

Existing and new competition ranked third and fourth, respectively, for both electroplating and coating/painting job shops.

A significant portion of the companies surveyed reported having recently invested in new equipment in response to customer demands for increased quality, quick turnaround, and lower prices. Among the metal finishing and manufacturing companies with more than 50 employees, 40% had purchased new equipment to improve quality and reduce costs:

- 37% purchased airless/air-assisted airless spray guns
- 29% purchased various types of equipment to improve productivity
- 12% purchased computer-controlled machining equipment
- 12% purchased ultrasonic cleaning equipment

Among the participating companies with fewer than 50 employees, 29% had made investments to improve quality and cut costs:

- 40% invested in quality improvement programs
- 20% purchased airless/air-assisted airless spray guns
- 10% purchased computer-controlled machining equipment
- 10% purchased automatic measurement equipment
- 10% purchased waste-burning equipment
- 10% purchased buffing equipment

Among electroplating and coating job shops, specifically, about 33% had invested in some new equipment in the recent past.

Knowing what a company or customer considers top priority for business development is one part of understanding what types of new equipment or services are likely to be adopted. It is also important to know who makes purchasing decisions and how decisions are made. EPRI's 1998 metal working study gathered information that provides useful insights about buying behavior among metal finishers and metals-related manufacturing firms.

In this industry, given the complexity of the processes and the product-specific nature of the production systems, equipment literature and visits by the vendor are generally inadequate to make a sale. Rather, most metal finishers require physical proof that a new piece of equipment or a system modification will work to their benefit before they will seriously consider its purchase. The evaluation process typically involves either seeing the new equipment/process demonstrated, or taking a product sample to a vendor for testing and having the vendor develop a customized process for the product. The industry is leery of off-the-shelf solutions.

TABLE 10. Company Decision Makers Relative to Company Size

Who Evaluates Equipment	Companies with < 50 Employees	Companies with > 50 Employees
Owner / President	84%	29%
Purchasing	7%	–
Plant manager/ Engineers	7%	57%
Corporate staff	–	14%

As shown in table 10, in companies with fewer than 50 employees, the company owner or president is the primary equipment evaluator (most companies in SICs 34–39 have fewer than 50 employees, and the majority of these have fewer than 10). In larger companies, specialized personnel, such as plant managers, engineers, and corporate staff become the evaluators.

UTILITY ROLE IN ANSWERING NEEDS

The EPRI survey also asked metals-related manufacturers and metal finishers if they felt utilities could play a useful role in providing them literature and information about technologies that might help them meet their customer demands. As shown in table 11, the responses fell along two lines, depending on company size. The facilities with fewer than 50 employees did not see a utility role; the facilities with more than 50 employees were open to receiving information, and some had an active interest in obtaining utility company input.

EPRI believes the low interest demonstrated by the smaller companies is not the result of

TABLE 11. Interest in Utility Information

Customer Response	Companies with ≤ 50 employees	Companies with ≥ 50 employees
Don't see a fit for the utility	70%	20%
Some interest in receiving information	30%	80%
Receptive to utility involvement	10%	30%

bad experience with utilities but, instead, indicative of the historic lack of business service contact with energy suppliers. In many cases, relationships with these small businesses may have been limited to meter reading. The larger companies, on the other hand, may have had direct contact with their electric utility. For example, they may be on a special rate plan or may have received advice on high-efficiency lighting. Overall, the lack of perceived value is believed to reflect a lack of awareness rather than a lack of need on the part of small companies.

Examples of positive interest include such statements from survey respondents as

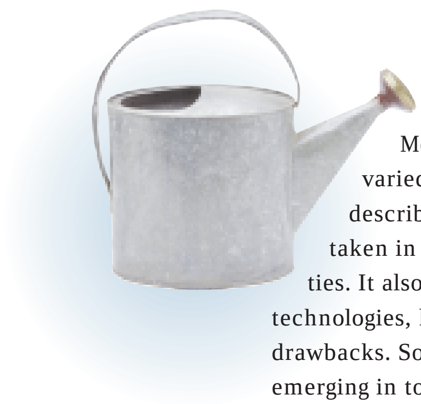
- "In our mind, there are not many areas of objective information. While the equipment manufacturers provide information, they are not objective. The utility can be objective."
- "The utility knows more about our business than other vendors know; they have a broad base of knowledge of multiple industries."

One reason given for little or no interest in utility input was lack of time: half of the survey participants who reported no interest said they would not have time or would be too busy to read any information sent to them. These respondents were in companies with fewer than 10 employees, the dominant company size in this market segment. Others said there was already plenty of information available; still others questioned what a utility might know about metal finishing.

Survey participants were also asked to state their level of interest in a utility-provided technology analysis/demonstration center, versus simply receiving "information" about a technology. Again the results show this market segment is dubious about utilities' ability to help: 25% of respondents were interested in local equipment demonstrations and process evaluation, 44% said they didn't know how a utility could provide such a center, and 31% felt certain their business operated in such a niche market, that a generic demonstration center could not help.

two

Processes and Technologies



Metal finishing is a broad and varied industry. This chapter describes the basic processes undertaken in most metal finishing activities. It also describes commonly used technologies, highlighting their benefits and drawbacks. Some newer technologies, just emerging in today's marketplace, are also discussed.

A familiarity with the processes and technologies summarized in this chapter provides a good foundation for understanding the nuances of the targeting method and service options described in chapters 3 and 4—but is not essential.

OVERVIEW OF METAL FINISHING PROCESSES

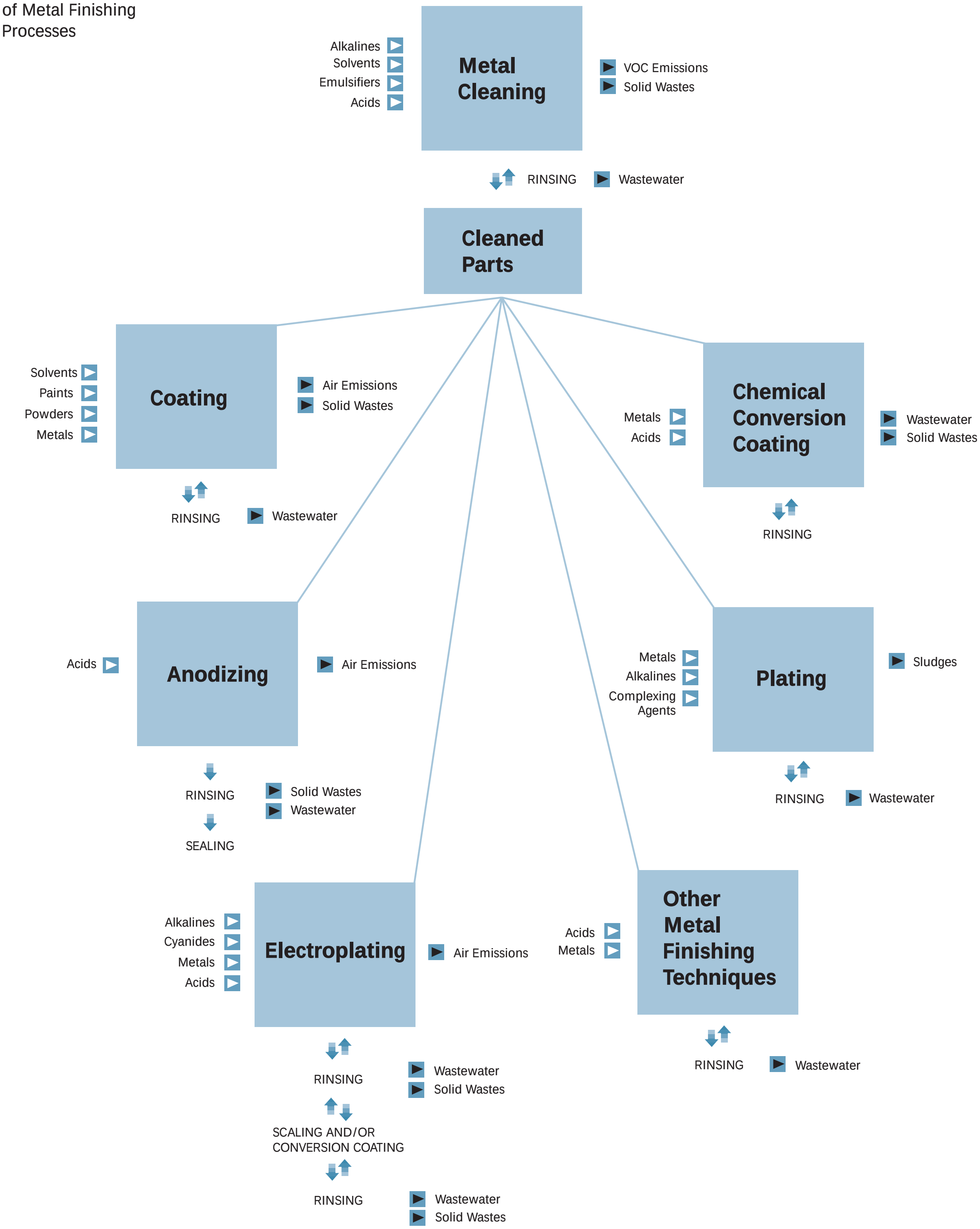
Metal finishing involves a series of processes that give the surfaces of manufactured metal parts desirable physical, chemical, and/or aesthetic qualities (figure 3). It is common for metal finishing facilities to combine several of these processes into one overall finishing activity (for example, to etch, then plate, and then coat a part to achieve the desired end product).

The large variety of possible substrate/finish combinations and specifications creates the potential for a complex nomenclature. The EPA groups the 46 processes it recognizes into the four process "families" identified below. These categories primarily reflect the types of wastes produced by each process group. It is useful to know this breakdown of finishing processes because they crop up in EPA literature and in publications of its associated pollution prevention programs.

- Inorganic finishing—the application of a metal coating onto a metal part (metal deposition or plating)
- Organic finishing—the application of paint and related materials onto a metal part
- Conversion—a finishing method, such as anodizing, phosphating, or chromating, in which the "plated" materials interact with and physically change the composition of a metal part
- Removal—a subtractive process that involves the removal of metal from the metal part either through physical action or chemical reaction

This guide categorizes processes according to their general method of application, utilizing common industry terms: chemical conversion, anodizing, plating, electroplating, painting, and powder coating. An overview of the most common processes of

FIGURE 3. Overview of Metal Finishing Processes



Source: EPA Office of Compliance, Sector Notebook Project, *Profile of the Fabricated Metal Products Industry*, 1995.

the late 1990s is described in this section, beginning with the preprocess step of metal cleaning.

Metal Cleaning

Prior to finishing, all metal parts are cleaned and prepared. Cleaning and other surface preparation operations are very important in determining the quality of the final finishing or coating process. To ensure a good bond with the finishing material, the surface of the workpiece must be properly cleaned and smoothed. Cleaning involves the removal of oil, grease, dirt, and oxidizes material from the surface of the workpiece using solvent or water (with or without detergent) or other dispersing agents. There are five key metal cleaning and surface preparation processes.

Alkaline Cleaning. Alkaline cleaning, a nonsolvent, aqueous-based cleaning process, removes oily dirt or solids from workpieces. The detergent nature of the alkaline cleaning solution provides most of the cleansing action, although agitation of the solution and movement of the workpiece increase cleaning effectiveness. Alkaline cleaners are used on soils that can be easily removed. Spray cleaners combine the detergent properties of the solution with the impact of a spray. Electrolytic cleaning produces the cleanest surface by strong agitation of the solution during electrolysis. In addition, some kinds of dirt particles become electrically charged during electrolytic cleaning and are repelled from the surface.

Acid Cleaning. Acid cleaning is an older process in which a solution of an acid, organic acid, or acid salt is combined with a wetting agent or detergent and used to remove dirt, oil, or oxides from metal surfaces. Acid cleaning is sometimes referred to as pickling, acid dipping, descaling, or desmutting. Heated acid solutions are also used in the process. Acid cleaning sometimes follows alkaline cleaning prior to plating.

Solvent Degreasing. Solvent degreasing uses organic solvents to remove oil and grease from the surface of a workpiece. It has been the industry workhorse because of its powerful cleaning, but solvents are an environmental liability. While the solvent can be applied in either liquid or vapor form, vapor degreasing is typically used because it is faster. Ultrasonic vibration is sometimes used in conjunction with liquid solvent degreasing processes. Emulsion cleaning is a type of solvent degreasing that uses common organic solvents in combination with an emulsifying agent.

Deburring. Deburring processes remove sharp edges caused by casting, machining, cutting, etc., during metal fabrication. Deburring usually involves mechanical abrading by grinding or tumbling metal parts in a large barrel filled with abrasive material (typically ceramic). A smooth surface is essential to achieving a long-lasting, quality finish.

Part/Paint Stripping. Stripping operations reprocess out-of-specifications parts or remove old coatings. Solvent, caustic, acid, or molten salt solutions are commonly used to strip old coatings. Electrically driven blasting systems are newer alternatives that employ a variety of manufactured and naturally occurring abrasives such as glass beads, agricultural products, plastic, and water to remove old coatings.

All cleaning processes result in solid and/or liquid waste that must be treated and disposed of properly.

Finishing Processes

Finishing involves altering the surface properties of a workpiece for resistance to corrosion and abrasion; increased electrical conductivity; better appearance, reflectivity, or solderability; and/or enhanced electrical resistance.

In production terms, finishing techniques are aqueous, dry, or paint-based processes. In aqueous processes, a workpiece goes through a series of concentrated chemical baths designed to produce the desired end product. The basic processes include conversion, electroplating, electroless plating, and mechanical (or contact) plating. Dry processes plate metals onto a workpiece; in many of these methods the coating changes from a solid to a vapor and then back to a solid after it is deposited on the workpiece. The basic processes include plasma spray, a variety of ion deposition techniques, and high-velocity oxygen fuel spray. Painting involves the deposition of a pigmented coating on the surface of a metal workpiece. Many metal finishers perform both plating and painting; often the two processes are performed on one piece to achieve the desired end product.

The following summaries of specific subtractive and additive processes are based on descriptions published in *Plating and Surface Finishing*, the journal of the American Electroplaters and Surface Finishers Society.

Conversion and Anodizing. Conversion processes are finishing methods in which plating materials interact with and physically change the makeup of the metal substrate. Conversion processes can serve as a final finish, because they provide excellent corrosion- and wear-protection, or as an additional preparation step prior to another finishing process, such as painting or coating. Common conversion methods include anodizing, chromating, phosphating, and passivation.

The processes and applications for conversion and anodizing are mature and basically nontoxic. By and large, the shops that perform these processes are well-established and specialize in these processes, only. Given the technological and marketplace stability, this type of metal finishing is not a focus in this guide.

Anodizing. Anodizing is specific to aluminum. The process is performed worldwide, is relatively inexpensive, and applies to products ranging from decorative to industrial. Anodizing is an electrochemical process that uses sulfuric, chromic, phosphoric, or other acids to convert the surface of an aluminum substrate to a coating of a hard, abrasion- and corrosion-resistant oxide film that provides superior protection and/or prepares the aluminum to receive secondary decorative (dye) or lubricant coatings. The chromic acid anodizing solution is considered hazardous because it contains hexavalent chromium, which requires treatment before discharge.

Plating and Electroplating. Mechanical or contact plating and electroplating are aqueous-based processes for depositing metal ions onto a substrate. Mechanical/contact plating uses direct contact with a metal-bearing solution; electroplating uses an electrical current; electroless plating uses chemical reactions. These processes work with a variety of metals and combinations of metal and are an extremely flexible and efficient means for giving metal substrates desirable properties.

Mechanical/contact plating involves the electroless deposition of a metal that is carried in a solution onto a substrate that is in contact with another metal. The contact metal anodically dissolves, and both the substrate and the excess contact metal become coated with the solution metal. The rate of deposition is rapid; it is possible to achieve a thicker coating with this method than with other coating techniques. Electricity is used to maintain a proper bath temperature.

Electroplating involves immersing an object in a plating solution charged by a suitable low-voltage electric current. The electric current causes an attraction between the metallic coating and the object. The process often involves a series of deposition and rinse steps to achieve the desired finish characteristics. Electroplating baths contain metal salts, alkalies, and other bath-control compounds in addition to plating metals. Many plating solutions contain metallic, metallo-organic, and organic additives to help refine the grain, level the plating surface, and brighten the deposits. Multiple depositions of different metals may be needed, with each metallic layer serving a different function in the finish.

Brass Plating. Brass plating was initiated in the mid-1800s; today it is the most widely used form of alloy plating. As an alloy of copper and zinc, brass electroplate results in deposits ranging in color from yellow to green to red to white. The major application for brass electrodeposits is hardware and lighting products, where it lends a decorative finish resembling solid brass. It is also used in the automotive industry. Posttreatment is common, used to further refine the look of the finish to achieve anything from bright brass to a currently popular “antique” sheen. Final lacquering is required because brass deposits are relatively soft and tend to tarnish. The use of cyanide in the process means solution handling and treatment requirements are fairly extensive.

Cadmium Plating. Cadmium coatings are applied by vacuum deposition, mechanical plating, and electroplating to protect steel against electrolysis. While zinc is preferred for protecting steel in industrial environments, cadmium is the best choice for marine environments. It is also favored for manufacturing certain aircraft, automotive, and electronics components. Cadmium is extremely toxic; plating solutions can give off toxic fumes and wastewater limits for new sources are considered difficult to meet using conventional technologies.

Copper Plating. Copper is electroplated using cyanide, acid sulfate, and pyrophosphate solutions. Cyanide-based solutions are used on a variety of base metals because they permit copper to adhere well to many metal alloys. For example, cyanide copper is applied as an undercoat for subsequent specialized electroplates in automotive, appliance, electrical, and plumbing industries, as well as the electronics industry. Both acid sulfate and pyrophosphate copper plating solutions are used in plating on plastics (following specialized surface preparation). Acid sulfate copper is the solution of choice in the printed circuit industry and is also used in plating steel wire, stainless steel cooking utensils, and zinc die castings. Pyrophosphate copper solutions are used in specialized manufacturing applications known as electroforming, and to plate zinc, aluminum, and steel die castings. Neither of the latter two plating solutions is particularly toxic or noxious; cyanide, however, requires extra precautions for handlers and specific treatment and disposal. Copper is also controlled by the EPA; routine waste treatment technology is generally successful in meeting requirements.

Decorative and Hard Chromium Plating. Chromium coatings are deposited by vacuum evaporation, sputtering, plasma spraying, and electroplating. Decorative deposits deliver a highly reflective finish, desirable on automotive trim, appliances, plumbing fixtures, and other consumer items. Hard chromium plating is an electroplating process that resists wear, abrasion, heat, and corrosion and is utilized for machine tool cutting surfaces, crankshafts, and artillery barrels, among other engineering applications. It is often the only finish that fulfills end-use requirements. Hard chromium deposits are significantly thicker than decorative deposits; the plating solution conditions are identical but a thicker coating is obtained by longer duration in the bath. Hexavalent chromium is highly toxic and hazardous. Trivalent chromium plating, developed 20 years ago, now provides an acceptable alternative, as does heavy electroless nickel in some applications.

Gold Plating. Gold has unique properties that make it the premiere choice for electronic interconnection applications; its use in decorative plating now accounts for just over 10% of the gold plating market. Strides in electronics plating equipment design and process formulations over the last 20 years, however, have minimized the amount of gold that must be deposited to achieve the desired performance from the coating. Some of these advances have led to more durable decorative gold plating for items such as watches and eyeglass frames. Gold is applied primarily by electroplating, because it is the most versatile technique, but also by thermal deposition, vacuum deposition, and mechanical rolling. Gold is renowned as the "ultimate" in corrosion-resistance, making any postplating process unnecessary. Gold is not toxic but many of the chemicals associated with gold plating are potentially hazardous; special handling is especially required for solutions involving cyanide and/or arsenic.

Nickel Plating. Electrodeposited nickel is versatile: it provides lustrous, bright decorative finishes, and great durability, when top-coated with chromium; provides corrosion, wear, electromagnetic, and optical properties in engineering finishes; and allows the manufacture of specialized tools and products through electroforming. Aqueous electrodeposition is most common; electroless, vapor deposition, thermal spray, conventional spray and roller coating, and powder spraying techniques are also used. Decorative nickel coatings are typically immediately plated with chromium—or with another type of metallic coating—to enhance corrosion resistance or achieve other surface effects. In engineering applications, nickel may be used alone and corrosion resistance controlled by the thickness of the nickel. Nickel and nickel-containing substances can be hazardous and/or irritating to skin and eyes. The EPA controls wastewater and sludge discharges.

Palladium Plating. In the late 1970s and early 1980s, palladium alloys were appreciated as low-cost alternatives to gold in electronics manufacturing. Today, palladium has proven itself an alternative that provides technological advantages as well. Palladium coatings are applied as pastes or by vacuum deposition, electroless plating, and electrodeposition. The choice of method depends on the specific end product (e.g., an electronic contact, connector, switch, capacitor, etc.). The two major classes of palladium and palladium alloys are ammonia-based (which include organic additives for a luster finish) and amine-based (additive-free, giving a bright to semibright finish). In most cases, palladium deposits are postplated with a thin layer of gold. Palladium and its complexes are generally safer than solutions used in gold plating; however, special attention to ventilation and protective clothing is required. Palladium is removed from spent bath water or rinse water by electrolysis or ion exchange resin.

Rhodium Plating. Rhodium is favored for a number of premium applications in jewelry and decorative work as well as production of electrical and electronics components. Due to its escalating price, however, its use is on the decline, replaced by palladium in decorative finishes and palladium-with-gold in electronics. Rhodium is almost always electrodeposited. It typically requires no post-plating treatment. Wastewater limits for rhodium have not been established. Because of its cost, great attention is given to recovery operations, usually achieved by direct plateout from dragout rinses followed by ion exchange treatment.

Silver Plating. Since the first patent for silver electroplating was granted in 1840, it has functioned as a durable decorative finish for the holloware and flatware industry. The chemical brighteners added to formulations today eliminate the need for polishing post-plating. Newer end uses include coatings on electrical connectors and semiconductor lead-frames, in both instances replacing gold. The typical plating solution is alkaline cyanide with organic brighteners; attempts to develop a noncyanide solution that delivers equally high-quality silver plating have failed. The presence of cyanide demands extra ventilation and protective gear; both silver and cyanide are controlled in wastewater releases. Using standard reclaim methods, it is typically cost-effective to reclaim silver from dragout and rinse systems.

Tin Plating. Tin is widely used—in finishing food containers, automotive parts, steel wire, electronics components, and printed circuit boards. It is nontoxic, corrosion-resistant, and malleable. Tin and tin-lead alloys are appreciated in the electronics industry for protecting a base metal from oxidation, thereby preserving its solderability. Tin is deposited mostly by electroplating, sometimes by hot dipping or by immersion. Proper ventilation is required around plating solutions and workers must wear protective gear. Tin is not currently regulated. Lead, however, is very toxic and wastewater discharges are controlled by the EPA.

Zinc Plating. Zinc coatings provide steel with protection against electrolysis and are preferred over cadmium coatings in industrial applications. Other popular uses include coating nuts, bolts, washers, metal stampings, and certain automotive parts. Most zinc deposits are electroplated; mechanical plating is used where hydrogen embrittlement of plated parts cannot be tolerated. Posttreatment with chromate is common to enhance corrosion resistance. Current developments include an effort to get away from cyanide-based plating solutions and to adopt alloyed coatings, primarily zinc-cobalt and zinc-nickel. All components of zinc plating solutions should be considered toxic and managed with extreme care. Protective gear is required for workers and both zinc fumes and dust are regulated, as are wastewater discharges and sludge.

Painting. Painting far exceeds plating in terms of the quantity of square footage treated. It is popular for a variety of reasons: lower cost, broader range of finish colors and textures, and better outdoor corrosion resistance (when applied over a pretreatment). These superior properties are reflected in increasing market demand for painting. Manufacturers often require a combination of plating and painting; full-service plating shops offer both processes. The dominant applications include the manufacture of automobiles, home appliances, and precoated stock metals (for subsequent forming). Paints are categorized by their formulation (solvent-based, waterborne, or powder); curing process (air-dried, baked, vapor-cured); function (undercoat, primer, topcoat); method of application (air spraying, airless spraying, electrostatic spraying, dip coating, flow coating, electrophorectic coating, powder coating). Of critical concern in the painting process is control of employee exposure to paint components, especially VOCs. Compliance solvents, waterborne paints, and powder coatings are new alternatives that do not trigger VOC restrictions. Powder coatings, especially, are now widely adopted by the industry. Some painting wastes are toxic and require controlled disposal. Excess solvents, paints, and sludges from water-wash spray booths, however, are safe for incineration.

Powder Coating. The global use of powder coatings is expanding at the rate of about 10% annually, making it the fastest growing method of finishing today. Powder coating is a dry process; typically, electrostatically charged particles of pigmented resin are sprayed onto a metal part, or the part is dipped in an air-infused "fluidized bed" of powder. After application, the powder must be heated to produce a paint-like coating. Powders comprise four basic elements: resins, pigments, extenders, and additives. The resins provide the base for the pigment; extenders add properties, such as edge covering, and minimize cost; additives produce other effects, such as reduced cure time or higher gloss. Powder manufacturers can customize blends to provide powders for almost every application—any color or gloss range, many textures and thicknesses. In powder manufacture, the components are mixed, ground, melted, remixed, extruded, and broken into powder. A powder must be used as-received; no on-site "tweaking" is possible. One drawback to powder versus fluid painting is the longer time required to clean a spray booth, application gun, and reclaim system.

Much of the growth in use of powder coating can be attributed to the excellent durability and quality of the coating, and the lower cost and high efficiency of the process. Additionally, this process produces less harmful emissions than conventional solvent-borne coating systems. During the manufacturing and application processes, few or no VOCs are emitted into the atmosphere, and waste is minimized by recycling overspray.

Polyester/TGIC. The most common powder coatings are the polyester/TGIC coatings originally used as clearcoats, and later as basecoats. These coatings show excellent durability with good impact resistance and, when covered with a clear coat, durability approaches five years. Some of the drawbacks are difficulty formulating a low-gloss finish and achieving very smooth coatings with thin films. Additionally, polyester/TGIC systems offer lower solvent resistance than the polyester/urethane chemistries.

Acrylics. Acrylic systems are an emerging technology in answer to manufacturers' more stringent weathering requirements. Acrylics offer the advantages of excellent weathering combined with lower temperature cure, distinctness of image, excellent gloss retention, and good salt-spray resistance. They are among the smoothest of all powder coatings in use today. The drawbacks to the acrylic chemistry include low impact resistance, poor flexibility, and incompatibility with other chemistries.

Polyester/Urethane. Polyester/urethane powder chemistry is not quite as smooth as acrylic but provides better flexibility and impact resistance. Powder coatings of this type offer good salt-spray resistance and gloss retention, hardness up to 4H-pencil strength, low-gloss matte finishes, as well as exceptional flexibility. The main disadvantage for urethanes is thick film limitations.

Epoxy. These are primarily used where exposure of the end product to ultraviolet (UV) light is minimal and gloss retention is not a concern. The advantages of epoxies include excellent chemical resistance, smoothness, corrosion resistance, adhesion, and good abrasion resistance. The primary disadvantage is poor UV resistance, which leads to chalking and loss of gloss.

Other Metal Finishing Processes. Electroless plating uses a plating solution to deposit a metal coating onto a metal substrate through chemical rather than electrical reactions. Electroless plating baths are extremely complex chemistries composed of plating metals, chelating agents to hold metals in solution, and a variety of other organic materials serving a number of different functions. Buffers, for example, artificially extend a pH range in solution. Inhibitors, on the other hand, prevent removal of substrate metal while allowing removal of oxides and reducing agents. Electroless plating operations require high-temperature baths and are therefore energy-intensive. Due to their complex chemistries, they also have special environmental and waste implications.

Electroless Processes. Electroless processes deposit a metal, commonly a nickel alloy or copper, onto parts by chemical reduction. Because no electrical current is involved, parts are plated evenly, even parts with complex shapes or deep recesses. Electroless nickel alloy and copper deposits have unique properties that are favored in engineering and electronics applications. The nickel alloys are frequently used for corrosion protection of aluminum and steel; nickel-phosphorus and nickel-boron alloys are common in the electronics industry. Post-plating heat treatment of electroless nickel alloy deposits increases their hardness. Electroless copper is utilized in the manufacture of printed circuit boards and for plating on plastics. These deposits are also commonly postplated. All electroless process solutions are hazardous and some are toxic for handlers; their wastewaters are considered hazardous by the EPA. Nickel emissions are regulated and nickel-bearing sludge is a hazardous waste.

Waste Handling Processes

Wastewater treatment, metal recovery, and sludge management are the primary environmental activities in the metal finishing industry.

Wastewater Treatment and Recovery. While conventional wastewater treatment technologies may still be sufficient to meet federal or local discharge standards, subsequent promulgation of tighter federal effluent standards, more stringent local limits, and challenges from combining wastewaters from various processes are beginning to create the need for more sophisticated treatment and recovery technologies.

General waste minimization techniques and practices are still the most productive and cost-effective strategies to reduce wastes at their sources and to improve the efficiency and effectiveness of treatment and recovery technologies. In a metal finishing shop, waste minimization practices include bath maintenance, dragout reduction, and zero water discharge.

Sludge Management. The hazardous sludge generated by the metal finishing industry has cost and liability implications for business owners and operators related to handling and disposal. To alleviate these concerns, metal finishers typically dehydrate or dewater sludge generated during the wastewater treatment process. Dewatering commonly involves a series of processes, including conditioning, thickening, dewatering, and drying. Each process reduces the percentage of liquid in the sludge.

Conditioning. Conditioning induces chemical or physical changes that enhance water removal in successive steps. Most conditioning systems cause small particles to bond into larger aggregates, thus increasing particle size and improving dewatering characteristics. The most widely used systems in the metal finishing industries are polymer and inorganic chemical conditioning. A few new technologies are under development, including mechanical freeze-thaw, electric arc treatment, and microwave systems.

Thickening. Thickening equipment increases the solids content of sludge 2–5%. Sludge is thickened mainly to decrease the capital and operating cost of subsequent sludge processing by dramatically reducing its volume. In the metal finishing industry, gravity thickening is the most commonly used method. Dissolved air flotation is a technology ready for implementation in this process. Other technologies, such as rotary drum thickeners, rotary thickeners, and sirex pulse power, are in the research and development stages.

Dewatering. The key contributor to sludge disposal costs is excess moisture. Dewatering reduces moisture in sludge, leaving a 10–60% solids content. The most widely used mechanical dewatering device in the metal finishing industry is the filter press. Technologies appropriate for this process include vacuum filters, centrifuges, belt presses, and membrane filter presses.

Drying. The primary purpose of drying is to produce a more manageable end product by reducing sludge volume and moisture content to achieve a 90% solids content. The low moisture content of the final product allows long-term storage with minimum concern for pathogen regrowth. In the past five years, sludge drying equipment has been one of the more frequently purchased pollution prevention and control systems. Electric resistance, electric infrared (IR), steam, and gas heat sources are used for sludge drying. Electric IR drying—well-known in other applications—is under development for applications in sludge management.

Process Selection and System Requirements

The needs of the metal finishing product end user (i.e., the specifications for the customer's product) determine which process a metal finisher chooses for a specific job, as well as the system requirements for the job. For example, plating for aesthetic purposes may require attention to the resulting color of the plated surface but not require a particularly clean subsurface bond. A production line performing such a process might have relatively few preplating steps. On the other hand, when plating for structural purposes or when a coating serves as the base for another plating process, the color may have little value—but the quality of the bond between the metal and the substrate may be critical. A production line conducting structural plating might employ extensive preplating processes and tight control of metal purity in the final plating tank.

Due to the highly specific needs of different end products, off-the-shelf equipment is rarely an option for metal finishers. Customization is often required. For example, using a vacuum deposition process to coat same-size rod stock in small batches can be a relatively simple process, requiring a $100,000 machine. However, using the same technology to coat parts of various shapes or parts having compound curves may require a $1 million machine.

Most equipment manufacturers rely on their distributors' day-to-day communications with metal finishers to know when to send out their design staff to specify a production line. Manufacturers design and build systems to fit a metal finisher's need according to the type of metal part being finished and the type of finish required. A design review often results in modifications to even the basic equipment. For example, plating tanks may be customized to match the size of the parts being treated; a tank too big or too small can lead to costly inefficiencies. The end result is a fully integrated system design, efficient as-is, and costly to modify if an unanticipated regulation requires some addition, such as a new filtration system. For example, one company discovered its ion exchange waste treatment system was incompatible with the chromium finishes it performed. Specifically, the plating bath solution had to be diluted and cooled before filtration to avoid damaging the filter resins.

OVERVIEW OF COMMON AND EMERGING ELECTRIC TECHNOLOGIES

Although the general chemical processes for coating and finishing are well understood, the application of new technologies allows for greater production capabilities, better control of finish characteristics, and/or reduced waste and pollution.

This section describes a selection of technologies applicable to metal finishing. Some of the technologies are fully commercialized and equipment is readily available; these technologies are described more completely in appendix A, Technology Profiles, and vendors are listed in appendix B, Equipment Suppliers. Other technologies are new and not widely available; these are qualified as "emerging" technologies.

The technologies are presented in the order of their application in the finishing/coating process. Each is identified with potential end-user benefits in terms of productivity, competitiveness, or environmental control. Competing technologies are also summarized. Many of the technologies for cleaning and coating are distinctly electrically driven with no fuel-switching potential. In plating processes, however, process baths are typically heated by natural gas. Most conventional curing/drying ovens are likewise commonly gas-driven.

Metal Cleaning Technologies

As described earlier, parts to be coated or plated require preliminary cleaning to remove contaminants that might interfere with the development of characteristic properties or product specifications. The selection of a cleaning system depends on a variety of factors, including the material being cleaned, the contaminants being removed, the level of cleanliness required, and the method of application. Traditionally, solvent-based cleaning methods have been most popular; these include vapor degreasing, cold cleaning (room-temperature solvent spray, dip, or wipe), and ultrasonic agitation. The phaseout of chlorofluorocarbon (CFC) solvents has forced metal finishers to evaluate alternative nonsolvent aqueous or semi-aqueous systems. Another alternative, nonhalogenated solvents, such as alcohols, ketones, and glycol ethers, are of limited use because of material compatibility issues, flammability concerns, longer drying time, emission of VOCs and HAPs, and waste disposal issues.

Aqueous and Semi-Aqueous Cleaning. Aqueous and semi-aqueous cleaning systems are popular alternatives to conventional cleaning with solvents and are now the surface preparation systems preferred by many metal finishers. Aqueous systems use heated mixtures of alkaline cleaners (alkaline salts with emulsifiers and surfactants); they are best used for cleaning insoluble particles and organic contaminants (e.g., oils, greases, abrasives, and waxes). Semi-aqueous systems combine a conventional organic solvent with water (and, in most cases, a surfactant) and are best used for cleaning heavily soiled parts and removing additional organic contaminants (e.g., rosin and flux). In contrast to conventional solvent cleaning, semi-aqueous cleaning allows the use of less solvent to achieve virtually the same cleaning effect.

Aqueous and semi-aqueous cleaning methods do not always remove dirt and grease as quickly or effectively as halogenated solvents such as 1,1,1-trichloroethane (TCA) or trichloroethylene (TCE). They also can extend the drying time needed after cleaning and increase water use and related water treatment/recovery requirements. These disadvantages prompted some initial resistance to the new cleaning approaches, although most shops have determined that the disadvantages are outweighed by the benefits of reductions in operating costs, regulatory burdens, and potential future liabilities.

This technology enhances environmental control. Competing technologies are existing sovent-based systems, such as vapor degreasing.

Ultrasonic Cleaning. Ultrasonic cleaning immerses metal parts in an aqueous or semi-aqueous solution and uses ultrasonic energy to displace contaminants. An electric generator supplies electricity to a transducer that converts the electricity to high-frequency sound waves in the cleaning solution tank. The compression and expansion of the fluid causes microscopic bubbles to form at the surface of the metal parts. The formation and subsequent collapse of these bubbles creates a scrubbing action and increases the reaction between the cleaning solution and the soils. This reaction takes the form of localized high pressure (near 10,000 psi) and temperatures close to 2000°F at the site of collapse. Because the pressure and temperature are localized, the cleaning tank itself does not heat up.

This technology enhances productivity and environmental control. Ultrasonic cleaning is unique and has no directly competing technologies. As a cleaning technology, however, it could be said to compete with solvent-based cleaning systems.

Emerging Cleaning Technologies

Vacuum Deoiling. In this technique, a vacuum furnace applies heat and vacuum pressure to vaporize oils from parts. Vacuum deoiling is a suitable substitute for vapor degreasing to clean metal parts. It also can remove oil from nonmetallic parts. Although capital costs for vacuum deoiling systems are high, the operating costs are low. One reason is that, unlike other cleaning technologies, the cleaned parts are not water-soaked and do not require drying. Because the time and temperature of the deoiling process depends on the material to be cleaned and the oil to be removed, system adjustments are needed for each new material, oil, or combination. Also, the parts must be able to withstand high temperature and vacuum pressure.

This technology enhances environmental control. Competing technologies are primarily solvent-based systems, such as vapor degreasing.

Laser Ablation. In laser ablation, short pulses of peak-power laser radiation are used to rapidly heat and vaporize thin layers of material off a surface. The hot, vaporized material forms a dense cloud that if not removed immediately will condense and recontaminate the surface. Ablation must be carried out in an inert gas environment to avoid contamination by other elements. Key benefits of the process include localized cleaning of a small area without affecting the entire part, and waste minimization (since no solvents or aqueous solutions are involved). The only waste is the material removed from the surface of the item being cleaned.

This technology enhances competiveness and environmental control. Competing technologies are primarily sovent-based systems, such as vapor degreasing, but also the physical contaminant removal methods such as grinding or tumbling, since laser ablation can remove soils and substrates.

Supercritical Fluid Cleaning. Supercritical fluids (SCFs) is a special category of pressurized gases that include fluids above their critical values for temperature and pressure. These fluids are flexible solvents because small alterations in pressure and temperature can produce significant changes in density, creating a corresponding change in the solvent power. They are characterized by high diffusivity and low density and viscosity, and are particularly effective at removing soils. The SCF cleaning process is compatible with stainless steel, copper, silver, porous metals, and silica. It leaves no solvent residue and has low operating costs. Capital costs, however, are very high.

Supercritical carbon dioxide has been tested as a potential replacement for CFC-133 and methyl chloroform, two common cleaning solvents. Supercritical carbon dioxide can dissolve many hydrocarbons, esters, silicones, perfluorinated soils, halocarbon-substituted triazines, and polychlor- and bromo-trifluoroethylene. Particulates such as lint, dust, metal, and salts can be dislodged by but are insoluble in supercritical carbon dioxide.

This technology enhances competitiveness and environmental control. Competing technologies are primarily sovent-based systems, such as vapor degreasing.

Plasma Cleaning. A plasma is an electrically charged gas containing ionized atoms, electrons, highly reactive free radicals, and electrically neutral species. Plasmas are created by passing an electric current through a process gas. They are characterized by high reactivity. Because process gases are inexpensive and nontoxic, this application has a relatively low operating cost. However, initial capital costs are high, and the equipment is highly specialized. Cleaning time can vary from minutes to hours, but all parts are cleaned evenly and equally well, regardless of their size or shape.

A plasma cleaning system consists of a reactor, radio-frequency generator, and a control system. The specific gas used in a plasma cleaning system depends on the components to be cleaned. The applications for plasma cleaning include removing organic contamination and residue from substrates, residues from plating baths and washing solutions, and coating from circuitry before repair.

The advantages of this process are low operating and disposal costs, but capital costs are very high.

This technology enhances competitiveness and environmental control. Competing technologies are primarily solvent-based systems, such as vapor degreasing.

Metal Finishing Process: Plating Technologies

Physical Vapor Deposition. Physical vapor deposition (PVD) of alternative materials is one candidate for replacing chromium electroplating. Hexavalent chromium is extremely toxic for handlers and is a known carcinogen.

PVD encompasses several deposition processes in which atoms are removed by physical means from a source and deposited on a substrate. Thermal energy and ion bombardment are the methods used to convert the source materials into a vapor.

The workpiece is placed in a vacuum chamber, and a very high vacuum is drawn. The chamber is heated to 400–900°F, depending on the specific process. A plasma is created from an inert gas such as argon. The workpiece is first plasma-etched to further clean the surface. The coating metal is then forced into the gas phase by one of the three methods described below:

Evaporation. High-current electron beams or resistive heaters are used to evaporate material from a crucible. The evaporated material forms a cloud, which fills the deposition chamber and then condenses onto the substrate to produce the desired film. Deposition of a uniform coating may require complex rotation of the substrate since the vapor flux is localized and directional. Despite this, evaporation is probably the most widely used PVD process.

Sputtering. The surface of the source material is bombarded with energetic ions, usually an ionized inert gas environment such as argon. The physical erosion of atoms from the coating materials that results from this bombardment is known as sputtering. The substrate is placed to intercept the flux of displaced or sputtered atoms from the target. Although sputtering is more controllable than evaporation it is an inefficient way to produce vapor. Energy costs are typically 3 to 10 times that of evaporation.

Ion Plating. Ion plating produces superior coatings adhesion by bombarding the substrate with energy before and during deposition. These atoms sputter off some of the substrate materials, resulting in a cleaner, more adherent deposit. This cleaning continues as the substrate is coated. The film grows over time because the sputtering rate is slower than the deposition rate. High gas pressure results in greater scattering of the vapor and a more uniform deposit on the substrate. This technique is sophisticated and rather costly; the only cost-effective application to date is electronics. Potential applications include biomedical implants and materials and high-performance battery materials.

This technology enhances competitiveness. Competing technologies are other plating techniques, such as chromium plating.

Metal Spray Coating. Metal spray coating refers to a group of related techniques in which molten metal is atomized and directed toward a substrate with sufficient velocity to form a dense and adherent coating. Metal spray coating has been used in a variety of applications. The technique avoids use of plating solutions and associated rinses, thereby reducing wastes. Cleaning of parts is still required prior to spraying.

The individual techniques vary mainly in how the coating is melted and in the form of the coating prior to melting. There are three basic means for melting the metal:

- Molten metal—The metal is heated by some suitable means (either resistance heating or a burner) and then supplied to the atomizing source in molten form.

- Fuel/oxidant—Oxygen/acetylene flames are typically used. The metal melts as it is continuously fed to the flame in the form of a wire or powder. The flame itself is not the atomizing source. Instead, the flame is surrounded by a jet of compressed air or inert gas that is used to propel the molten metal toward the substrate.
- Electric arc—In this method an electric arc is maintained between two wires that are continuously fed as they melt at the arc. Compressed air atomizes the molten metal at the arc and propels it toward the substrate. CD plasma arc spraying and vacuum plasma spraying are variations of this technique in which an inert gas (usually argon) is used to create a plasma between the electrodes.

The technologies for thermal spraying of metals are well developed. They have their own market niche and are not typically thought of as a replacement for electroplating. As the costs of hazardous waste treatment and disposal rises, however, this family of techniques may become a cost-effective replacement for coating applications currently performed by electroplating. The coatings can be applied to a range of substrates including paper, plastic, glass, metals, and ceramics with choice of suitable materials and control of the coating parameter.

This technology enhances competitiveness and environmental control. Competing technologies are other plating techniques, such as chromium plating.

Emerging Metal Finishing Process: Plating Technologies

Low-Temperature Arc Vapor Deposition. The low-temperature arc vapor deposition (LTAVD) process deposits a variety of functional and decorative metallic coatings on virtually any substrate, from metals to plastic. LTAVD is a physical vapor deposition process that employs a high-current, low-voltage electric arc to evaporate essentially any electrically conductive material. The deposition process is operated in a highly controlled vacuum to deposit adherent, dense, thin-film coatings.

LTAVD has a number of advantages over other physical vapor deposition techniques, as well as benefits not found in chemical vapor deposition. LTAVD coatings are highly adherent as well as resistant to wear and corrosion. Also, LTAVD can coat at room temperature or higher and does not add significant heat to the substrate, reducing the chance of damage due to loss of temper, deformation, or a change in crystal structure.

The process is highly productive; deposition occurs over a 360-degree field rather than the 180-degree field of standard vacuum deposition processes. Thus, parts being coated are always in the coating plasma, a significant advantage for film quality and deposition rate. Coating rates and uniformity are excellent. Film thickness varies from 300 angstroms to a few mils, depending on what is specified.

Electrodes can be configured in any shape necessary to accommodate the parts being coated. Because there is little waste heat and low thermal radiation, the process allows the deposit of materials with high melting points onto substrates with low melting points. For example, high-melting-point metals such as tungsten can be applied to plastic films. Another advantage is that dissimilar materials can be alloyed using LTAVD, and materials not commercially available can be deposited. This is useful for compounds such as titanium/aluminum and others that have different melting and evaporation points.

The LTAVD process is safe for the environment and workers: no VOCs or hazardous or toxic materials are produced. The only effluent generated is vaporized oil from the vacuum pumps; however, most of this is captured in a cold trap that condenses the effluent and separates out the oil.

This technology enhances competitiveness and environmental control. Competing technologies are other plating techniques, such as chromium plating.

Nickel-Tungsten-Silicon Carbide Plating. The nickel-tungsten-silicon carbide (Ni-W-SiC) composite electroplating process is a patented process that can be used to replace hard chromium coatings in some applications. Nickel and tungsten ions become absorbed on the suspended silicon carbide particles in the plating solution. The attached ions are then adsorbed on the cathode surface and discharged. The silicon carbide particle becomes entrapped in the growing metallic matrix. This technology is especially effective for producing long-lasting cutting tools and drills.

This technology enhances competitiveness and environmental control. Competing technologies are other plating techniques, such as chromium plating.

Nickel-Tungsten-Boron Alloy Plating. Following several years of development, a new chromium alternative based on an alloy of nickel, tungsten, and boron is now being introduced to the market. A family of these alloys is patented under the trade name AMPLATE.

Unlike most metals, which exhibit a crystalline structure at ambient temperatures, the AMPLATE alloys are structureless. Metals of this type are often described as "amorphous," and have "glasslike" properties that render substrate surfaces smooth and free of the defects that are exhibited by lattice-structured metals. Because of the smoothness and hardness of their surfaces, amorphous metals have excellent corrosion- and abrasion-resistance properties. And because the deposit remains bright and smooth the need for grinding and polishing is greatly reduced. This improves productivity and enhances product quality.

This technology enhances competitiveness and environmental control. Competing technologies are other plating techniques, such as chromium plating.

Metal Finishing Process: Coating Technologies

Coating processes add decorative and/or performance coatings to metal substrates and are used in a variety of industries, including the manufacture of automobiles, household appliances, and furniture—anything that is painted prior to final sale.

To improve transfer efficiency and reduce paint waste, many metal finishers are switching not only to alternative coatings, (e.g., high-solids, waterborne, powder, and ultra-low/nonsolvent coatings) but to alternative application technologies. Conventional spray technologies have a transfer efficiency of approximately 25%; many alternative application technologies have significantly higher transfer efficiencies.

Nonspray systems, such as dip coating, roll coating, curtain coating, flow coating, and tumbling, have high transfer efficiencies; however, they may not be useful for parts that traditionally have been sprayed because all surfaces become coated.

Compressed-Air Atomization. Compressed-air atomization, a method of paint application, is an elder system, having come into existence in the early part of the twentieth century. This process has two primary advantages. It is the most controllable finishing system—the spray pattern can be adjusted from a small dot to a large elliptical pattern several feet wide—and the degree of atomization can be adjusted from a fine finish to a coarse finish. This process is also the most versatile. It can spray almost any coating at any reasonable speed with ease of operation.

The disadvantages of compressed-air atomization include its poor transfer efficiency. In most applications, more material is wasted than actually deposited on the intended surface. Low transfer efficiency due to the turbulence of the high air pressure leads to excessive paint waste, frequent and costly spray booth filter replacement and waste disposal costs, and violation of federal pollution minimization laws.

Recently, stricter emissions regulations have forced finishers in many areas of the country to change to more efficient spray systems. Several new processes have recently emerged that offer great potential. Descriptions of these processes follow.

This technology enhances productivity. The primary competing technology is powder coating. However, other spray coating processes such as HVLP and airless spraying are also competing technologies.

High-Volume, Low-Pressure Atomization. The high-volume, low-pressure (HVLP) atomization process for paint application works similarly to conventional air spraying, with two notable exceptions. First, jets of high-pressure, low-volume air exiting a nozzle are replaced by soft columns of high-volume, low-pressure air. Secondly, larger interior diameter air hoses feed specially constructed spray guns that restrict the atomizing air pressure within the spray gun or within the hose itself. Finally, air used to atomize the coating originates either from high-speed turbine-operated blowers or from existing air compressors.

HVLP systems operate at 15–301 cfm and 1–10 psi to atomize a soft, highly efficient air spray. Although exceptions exist, many turbine-operated HVLP systems have found a home in smaller finishing operations, due in part to their portability. Air-restricted HVLP systems have become popular in larger plants because of their ability to use existing shop air, keep up with moderate production speeds, and spray higher solids coatings. Newly released HVLP air-assisted airless spray guns allow for higher production speed while also giving users HVLP compliance when necessary.

This technology enhances productivity and environmental control. Competing technologies are other spray coating processes, such as airless and electrostatic spraying.

Low-Pressure, Low-Volume Atomization. Low-pressure, low-volume (LPLV) air atomization atomizes paint with jets of low-pressure, low-volume compressed air strategically impinged to exit the spray gun as a flattened cross-sectional fluid stream. LPLV can also be considered a low-pressure air-assisted airless spray system.

Fluid pressure ranges from 20–70 psi, air pressure from 5–15 psi, and air volume consumption from 3–8 cfm, obviously low pressure compared to air-assisted airless spraying and compressed-air atomization processes.

This coating application method offers advantages such as high transfer efficiency (65–75%), reduced bounceback even when spraying into recesses, reduced material costs, lower emissions, reduced booth maintenance and hazardous waste costs, and ease of operation.

This technology enhances productivity. Competing technologies are powder coating and other spray coating processes.

Airless Spraying. Airless spraying was developed in the early 1960s. As the name implies, this method does not use compressed air to develop a spray pattern. Instead, hydraulic pressure is used to atomize paint by forcing it under high pressure (600–4000 psi) through a small-orifice spray nozzle tip of a specialized airless spray gun.

As the coating is released into the atmosphere it is sheared into tiny droplets that reach the part surface by momentum. The amount of material exiting the tip is controlled by the tip's orifice and the pressure and viscosity of the coating. The size of the spray pattern is controlled by the angle drilled into the tip.

The main advantage of airless spraying is its speed: it is the fastest method of atomization available. Other advantages include less bounceback, the ability to spray into recessed areas, and the ability to spray heavy coatings in outdoor environments.

The main limitation of airless atomization is its coarseness, which makes it inappropriate when a fine finish is desired. However, not all situations call for fine finish. Anticorrosion coatings are an example.

This technology enhances productivity and environmental control. Competing technologies are powder coating and other spray coating processes, such as airless and electrostatic spraying.

Air-Assisted Airless Spraying. Recent developments in finishing equipment include this process, which combines two finishing processes for paint application. Air-assisted airless spraying, when used under ideal conditions, employs the best features of compressed air and airless spraying. This method uses a specially designed gun and pump. Fluid is delivered to the spray gun at medium pressures (150–1000 psi), where it is approximately 80% atomized by an airless tip. Atomization is completed by introducing low amounts of atomizing air (5–30 psi) into the spray pattern.

The result is a finely atomized pattern that closely resembles that of compressed air. This process also reduces fog and overspray, allows spraying into recesses, provides a higher film build per pass, and consumes up to 50% less air than an ordinary compressed-air finishing system. The benefits include improved transfer efficiency and costs savings. The process of electrostatic air-assisted airless spraying provides even greater transfer efficiencies.

This technology enhances competitiveness and environmental control. Competing technologies are powder coating and other spray coating processes, such as electrostatic spraying.

Electrostatic Spraying. Electrostatic application of coatings is highly advantageous for finishing metal products with either paint or powder coating. The high transfer efficiency of electrostatic spray finishing not only saves material but significantly reduces VOC levels in the exhaust from spray booths (because less coating is used). Electrostatic spraying is one option for metal finishers who are forced to reduce VOC emissions because they are located in regions of the United States classified by the EPA as nonattainment zones.

The operation of an electrostatic spray gun is simple. The coating is charged by a high-voltage, low-amperage direct current either before or immediately as it exits the spray gun. The object to be painted must have an opposite charge for the paint to collect on the areas that would normally not be coated, such as the sides and back. The net result is improved transfer efficiency.

As with other spray equipment, electrostatic applicators are constantly undergoing improvements. Smaller, safer, more maneuverable hand guns are now in use. Some even use air-operated turbines mounted directly on the spray gun that provide the necessary voltage. This eliminates a high-voltage power supply and cable to the gun. Electrostatic HVLP is also available for operations that require high transfer efficiency along with electrostatic "wrap."

The developments of compact, high speed, electrostatic rotary bells and discs are adding a new dimension to this method of applying coatings. Transfer efficiencies as high as 95% are possible with these units. This equipment also makes it possible to effectively atomize the popular new high-solids and waterborne coatings.

This technology enhances productivity and environmental control. Competing technologies are other spray coating processes.

Plural Component Spraying. Rapid growth in the use of plural component materials such as polyesters, epoxies, and polyurethanes in advanced paint formulations has led to new equipment for precise metering, mixing, and dispensing of the two or more components. Plural component spraying equipment ranges from simple but accurate metering pumps delivering a given ratio of materials, to highly sophisticated computerized systems that allow selection of a range of component ratios and accurately monitor and report each step of the finishing operation. The spray guns must mix the two component coatings either internally or externally, depending on the chemical formulations used. The ratio between the component materials can be fairly equal or far apart. Plural component spray guns and pumps must be designed to accurately handle these ratios.

This technology enhances competitiveness. Competing technologies include some metal plating technologies, such as anodizing and zinc plating, as well as other coating technologies, such as powder and dip coating.

Curing and Drying Technologies

Process heat is required for a number of metal finishing processes, including drying and curing and, in some cases, heat treating, heating, and preheating. Electric infrared (IR) drying and ultraviolet (UV) curing are among the technologies available for drying and curing processes. Induction heating and indirect resistance heating are two technologies available for heat treating, heating, and preheating metal parts.

Electric IR Drying/Curing. IR radiation is produced by conducting an electric current through a filament. The radiation is absorbed by the coated product, causing its molecules to vibrate and generate heat. The heat dries the coating from the inside out. The system requires no special airflow for heat transfer because energy radiates directly to the coated surface without heating the air. By localizing the origin of emissions, and allowing the use of reduced- or nonsolvent coating, the technology enables metal finishing shops to significantly reduce or eliminate VOC emissions.

The productivity of a metal finishing shop is partially dependent on the rate at which materials dry. IR curing can cut drying time and boost productivity; additional advantages include improved energy efficiency, space savings, precise process control, low maintenance requirements, improved product quality, and reduced environmental impact. The use of IR curing is growing as metal finishers look for ways to reduce VOC emissions and improve both productivity and product quality.

This technology enhances productivity and environmental control. Competing technologies are primarily passive air drying and existing ovens heated by natural gas or by electric resistance coils.

Ultraviolet Curing. UV radiation can induce a rapid transformation of a liquid to a solid coating through a change in its molecular structure. Specialized "radiation-curable" coatings cure almost instantaneously when exposed to UV radiation. UV curing has a number of advantages, including reductions in labor, space, and energy requirements; no solvents; less heat production; and exceptional performance in terms of color density, gloss, and durability.

Although introduced in the 1960s, UV curing has attracted only a small percentage of the metal finishing market. Today, however, use of UV technology is growing rapidly because it offers a means to reduce VOC emissions while improving both productivity and product quality.

This technology enhances productivity and environmental control. Competing technologies are primarily passive air drying and existing ovens heated by natural gas or by electric resistance coils.

Waste Handling Technologies

Today's typical metal finishing facility utilizes a variety of equipment to handle wastewater treatment, metals and solution recovery, and sludge.

Technologies are available to recover chemicals and metals from wastewater prior to discharge and, in some cases, to recycle solutions and bath and rinse waters for reuse. The most common and preferred method of metal removal is chemical precipitation of the metal as a hydroxide, sulfide, or carbonate. Precipitation involves altering a wastewater's chemical equilibrium by exceeding the solubility levels of unwanted metals. Lime or sodium hydroxide is typically added to the wastewater to raise the pH until it reaches the metal's minimum solubility. The dissolved metal is then transformed into a solid, making it easier to remove.

While advanced treatment and recovery technologies have been developed, the majority of metal finishers continue to use chemical precipitation. Chemical precipitation attains compliance in most cases. It is in those cases where compliance requirements cannot be met with chemical precipitation alone that more advanced, innovative technologies are adopted, either by themselves or in combination with chemical precipitation. These technologies include ion exchange, electrolysis, and membrane filtration.

Ion Exchange. Ion exchange removes metal and chemical ions from solution by passing rinse waters through resin beds. The resin beds exchange a hydrogen or sodium ion for a metal or chemical ion. Treated water can then be recycled. When the resin beds are filled and can no longer exchange more ions, the unit can be regenerated by passing an acid solution through the resin to reexchange metal and chemical ions for hydrogen or sodium ions.

Ion exchange units are modular and can easily fit into available space in most shops. The advantages of ion exchange include its ability to work well with low concentrations of recoverable materials, long equipment life, and low downtime. In addition to recovery of metal ions and chemicals, ion exchange can also remove trace pollutants and be used to purify water for process baths and rinse waters. However, in both recovery and purification applications, ion exchange generates acid waste residuals that must be neutralized and disposed of properly.

This technology enhances environmental control. Competing technologies are waste handling systems such as chemical precipitation, and other membrane-based technologies, such as electrolysis.

Electrolysis. Electrolysis is becoming an increasingly attractive option for metal finishing wastewater treatment. Electrolysis can be used to recover metals from a primary rinse bath, treat wastewater leaving a second rinse before ion exchange, or to treat ion exchange regeneration effluent. This electrochemical process strips spent plating and rinse water of its dissolved metal ions by passing an electric current through the wastewater, so that the metal ions deposit as a solid metal onto a series of cathodes that have especially high surface areas available for deposition. The loaded cathodes can be sold for their metal value. When placed in the static rinse bath close to the source of metal emissions, an electrolysis unit can remove more than 90% of the metal.

The primary advantage of electrolysis is the elimination of sludge and the costs and liabilities associated with its disposal. Other advantages include efficient operation at both high and low concentrations of metals, minimal maintenance, and oxidation of organic additives (e.g., cyanide) at the anode (into carbon dioxide, nitrogen, and water). However, some compounds, including iron and chrome, prevent high recovery levels due to their ability to interfere with the electrochemical efficiency of the unit. Other metals, including barium, titanium, and tungsten, are not recoverable electrochemically.

This technology enhances environmental control. Competing technologies are waste handling systems such as chemical precipitation, and other membrane-based technologies, such as ion exchange.

Membrane Filtration. The membrane filtration processes of microfiltration, ultrafiltration, and reverse osmosis use permeable membranes to filter selected components from liquid mixtures. Each filtration system differs in the size of the particles allowed through; microfiltration allows larger molecules, and reverse osmosis allows only the smallest. In metal finishing, all three processes can be used to separate out metals and other contaminants from bath and rinse waters, thus permitting reuse of water and chemicals. Reverse osmosis is used primarily to separate metals and chemicals from rinse waters; microfiltration can regenerate both cleaning and process baths; and ultrafiltration can be used as an additional treatment step prior to reverse osmosis or after microfiltration. The main disadvantages of membrane filtration technologies include their high initial capital investment costs, requirement of periodic membrane replacement, and generation of residual sludge that must be disposed of.

One variation, cross-flow microfiltration (CMF), effectively removes suspended particles, metal hydroxides, and many organics; CMF performs solid-liquid separation with the solution flowing across—not through—the membrane. This process reclaims metals to enable recycling and reuse of water, and greatly reduces the amount of sludge produced. CMF can also be used to upgrade a wastewater treatment system to meet more stringent compliance requirements without having to purchase a whole new treatment system.

This technology enhances environmental control. Competing technologies are waste handling systems such as chemical precipitation, and other filtration technologies.

Vacuum Evaporation. This process uses closed-loop, low-temperature vacuum distillation and evaporative recovery for wastewater treatment and recovery. In vacuum evaporation, rinse water is heated under vacuum. The water is vaporized off, rising through a mist separator where particulate matter is removed. A cooling coil condenses the steam, and distilled water forms in the reservoir to be recovered for reuse or discharge. As the water is driven off in the vacuum, dissolved salts are concentrated; these contain valuable chemicals that can be collected and returned to the process tank.

The primary advantages of vacuum evaporation are the virtual elimination of water discharge—eliminating compliance problems and minimizing water use—and reduction of the volume of sludge or concentrate requiring hauling, treatment, and disposal. The process also reduces air pollution problems and enables the recovery of both temperature-sensitive baths and solutions with volatile components. However, because of the high initial investment required, the purchase of a system is largely dependent on the amount and type of chemicals available for recovery.

This technology enhances environmental control. There are few competing technologies for this unique filtration system. Depending on the application, chemical precipitation can compete with vacuum evaporation.

Toxic Chemical Replacement

Replacement of cyanide, cadmium, and hexavalent chromium in plating shops greatly reduces safety risks to workers. These chemicals are extremely toxic and electroplaters are at risk for exposure through skin contact, ingestion, and inhalation. They are also longstanding mainstays of the metal finishing industry, but new processes are available that are proving successful alternatives.

Titanium Nitride Replacement for Chromium. Titanium nitride is a prime candidate for replacing chromium coatings using PVD. Titanium nitride is much harder than chromium so it can be cost-effectively applied in much thinner coatings. However, because of the thin, hard nature of the coating, titanium nitride is inferior to chromium in applications where the metal product will be subject to a high load. Titanium nitride coatings also do not provide as much corrosion protection as thicker, crack-free chromium coatings.

This technology enhances competiveness and environmental control. Competing technologies are existing plating practices such as chromium plating.

Ion Vapor Deposition of Aluminum. In ion vapor disposition (IVD), the coating metal is evaporated and partially ionized before being deposited on the substrate. A typical IVD system consists of a steel vacuum chamber (measuring 6 feet in diameter by 12 feet in length), a pumping system, a parts holder, an evaporation source, and a high-voltage power supply.

Aluminum coatings deposited through IVD can replace cadmium coatings in some applications, thereby eliminating the use of both cadmium and cyanide. Aluminum is considered nontoxic, and IVD itself does not employ or create any hazardous materials.

The evaporation apparatus consists of a series of concave ceramic "boats" through which a thin strand of aluminum wire is continuously fed. These boats can move back and forth between the parts to ensure even coverage. A high current supplied to the boat melts and vaporizes the aluminum. Once evaporated, the aluminum atoms collide with high-energy electrons in the chamber and become ionized. The positively charged aluminum ions accelerate toward the negatively charged substrate, condensing to form a protective metal coating.

The coating process itself takes 1 to 2.5 hours, depending on the configuration of the parts and the desired coating thickness.

This technology enhances productivity and environmental control. There are no competing technologies for most applications of IVD.

Noncyanide Copper Plating. Noncyanide copper plating is an electrolytic process similar to its cyanide-based counterpart. Operating conditions and procedures are similar, and existing equipment usually will suffice when converting from a cyanide-based process to a noncyanide process.

Noncyanide copper plating baths are commercially available for coating steel, brass, lead-tin alloy, zinc die cast metal, and zincated aluminum. Other applications include fasteners, marine hardware, plumbing hardware, textile machinery, automotive and aerospace parts, masking applications, electromagnetic interference (EMI) shielding, and heat treatment stop-off. The process is compatible with rack or barrel set ups and can be applied as a thin deposit (a "strike") or as a heavy plate.

Noncyanide copper plating baths are typically formulated by manufacturers of bath solutions. Chemical compositions and their formulae are proprietary information. As a result, very little has been published on development activities. According to one manufacturer, product improvement efforts will continue for some time, although no major new developments are expected.

This technology enhances environmental control. Competing technologies are existing copper plating processes.

Noncyanide Metal Stripping. The use of cyanide-based metal strippers results in the generation of cyanide-contaminated solutions that require special treatment and disposal. Noncyanide strippers are less toxic than their cyanide-based counterparts and more susceptible to biological and chemical degradation, resulting in simpler and less expensive treatment and disposal of spent solutions.

The noncyanide stripper technology has been available for many years but is only now gaining interest. Its major drawbacks include slower stripping speed, etching of some substrates, and the need for electric current. As the disposal costs continue to escalate, however, for spent solutions from cyanide-based strippers, many companies are switching to noncyanide stripping methods. These companies must adjust their production cycles to account for the slower stripping speed.

This technology enhances environmental control. Competing technologies are existing cyanide-based stripping systems.

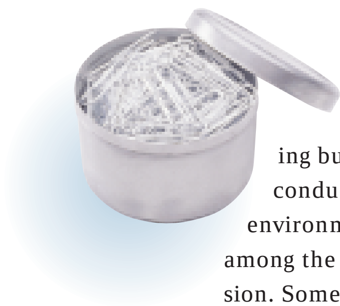
Zinc-Alloy Electroplating. Alloys of zinc can be used to replace cadmium coatings in a variety of applications. Cadmium is a heavy metal that is toxic to humans. In addition, electroplated cadmium coating processes normally are performed in plating solutions containing cyanide. Use of both cadmium and cyanide can be eliminated by substituting an acid or noncyanide alkaline zinc-alloy coating process for a cyanide-based cadmium electroplating process.

The ability of any alternative coating to replace cadmium depends on the properties required by the application in question. Some zinc alloys have as good and, in some cases, better resistance to corrosion, as measured in salt spray tests. However, few match cadmium for natural lubricity in applications such as fasteners. In addition, where cadmium is selected for its low coefficient of friction or for its low electrical contact resistance, none of the candidates mentioned above may be suitable.

This technology enhances productivity and environmental control. Competing technologies are other plating processes, such as cadmium plating and also some coating technologies, such as plural component spraying and powder coating.

three

Targeting Assistance to Metal Finishers



Energy suppliers are turning their attention toward developing business and marketing strategies conducive to success in a deregulated environment. Small-business strategy is among the important issues under discussion. Some questions utility strategists are considering include

- Should our company do anything to try to retain small-business customers?
- If we don't, what portion of our small-business customers will we lose?
- If we run a program, what should we offer besides price to keep them?
- What do small-business customers value?
- What services might they value if provided by a utility?
- Can our company make money offering new services for these customers?

These are broad questions for examination at the strategic level. A utility that decides to move ahead with creating and offering specialized programs and services for small-business customers must 1) decide what to offer and 2) assess internal resources to ensure it has the capacity to provide the desired services.

This guide addresses energy suppliers that are actively surveying their options to sustain a strong small-business customer base—especially by retaining companies engaged in metal finishing.

UTILITY SERVICE OPTIONS AND INTERNAL RESOURCES

A number of service options can be proposed for almost any type of small business, whether offered for "free," for a fee, or through a performance contract agreement. A set of generic service offerings is outlined in table 12. Many of these services might be attractive to and appropriate for metal finishers. Most valued, however, are service offerings that answer a target customer's specific needs and interests.

As discussed in chapter 1, uppermost in the minds of metal finishers is the need to identify and invest in the mix of technologies that will lead to competitiveness, productivity, and environmental compliance in the simplest and most inexpensive way possible. Knowing this cuts through a lot of potential guesswork about what these customers might value. However, the ideal technology mix will differ from facility to facility, since every firm faces a unique set of circumstances based on the types of finishing it does, the finishing markets it serves, and its specific regulatory context.

TABLE 12. An Overview of Service Options

Service Options	Energy Services	Technology Services	Business Services
No cost to customer	"Easy to do business with" Information on energy topics Energy usage data Billing options	Information support: • technology application • technology sources • technology information sources	Informational clearinghouse: • operational issues • regulatory issues
Fee-based	Power quality Energy audits Specialized metering Equipment reviews Lighting audits and retrofits Service contracting (e.g., HVAC)	Technology consulting: • technology application support Technology project management	Subscription services on key topics: • operational • regulatory Construction design assistance Equipment financing Outsourced business services (e.g., HVAC management, EPA compliance management)
Partnership or third-party contract	Power quality Energy-based performance contracting Lighting retrofits	Equipment performance con tracting—sharing the payback on technology investments	Outsourced business services: • HVAC management on a performance contract basis • EPA compliance management on a performance contract basis

Source: QDI Strategies, Inc.

More detailed information is needed to determine the particular technologies or processes—and the related service offerings—that might best benefit a target customer.

Three-Level Analysis

This chapter presents a strategy for collecting information and targeting assistance to metal finishers. It introduces a three-level method for evaluating a metal finishing firm's business viability and readiness for change, focusing on process improvement opportunities. Each level provides a sequentially deeper analysis to guide decision making on whether and how a particular firm or group of firms might respond to utility service offerings.

At the first level, energy suppliers can analyze metal finishing firms for their long-term viability, with the assumption that companies that are "under attack" from too many directions will ultimately fail regardless of any assistance they receive (unless they make extraordinary efforts to reorganize themselves). The second level is an "opportunity analysis," to assure that companies are actually in need of process improvement assistance and that well-qualified opportunities exist and are easily available for implementation. This reduces the risk of working with firms that are already using fairly advanced technology or that have intrac–table problems that can only be solved by basic, and therefore expensive, research. The third level analyzes firms for their willingness and ability to undertake process improvement investigations and implementation. These three levels of categorization allow energy suppliers to screen and target metal finishing companies for assistance, thus ensuring a higher level of payback for the effort expended.

Note that the three-level analysis presented here is not exhaustive but rather a means for narrowing a population of metal finishers for marketing purposes. The business data needed for the analysis might be collected through telephone or face-to-face interviews with local customers, focus group interviews with local customers, in-depth interviews with local trade allies and/or trade organization representatives, or through analyzing data accumulated by service representatives' contact with metal finishing companies. The next step, for firms identified in this analysis as needy and receptive to change, is a rough screening for specific services of value; i.e., specific process improvements and the implementation assistance needed to achieve the improvement. The types of assistance an energy supplier might offer a metal finisher to support the process improvement are also identified. This step is presented in the latter half of this chapter.

Internal Resources

Commitment at the senior management level to apply resources toward the goal of retaining small-business customers is the essential first step, and amassing in-depth information on targeted customers supplies critical input, but to achieve strategic goals through new service offerings requires a well-conditioned set of skills. This skill set, "organizational readiness requirements," is depicted in table 13. A self-score, using this table, helps assess a utility's readiness to launch new products and services—successfully. A score of 10 is possible for each of the five "requirements" categories. A score of 10 indicates the capability is in place and ready to go to support the launching of a new program. A score of 5–9 suggests the necessary capability can be put together within 12 months. A score of less than 5 suggests this capability has been low priority. A composite score over 40 would be excellent; a score of 26–39 would be good. A total score of 11–25 would indicate a very weak support system for a program launch. A total score of 10 or less suggests the appropriate next step might be to develop a timeline for meeting the requirements—rather than risk starting a program.

LEVEL 1 ANALYSIS: Long-Term Trends Affecting Business Viability

The metal finishing industry is marked by strong rivalries and price competition. Many companies can provide the same finishes, such that some services are largely undifferentiated among providers. If any differentiation does exist or if demand for a certain type of finish increases, finishers with the financial capacity can make incremental investments in different finishing processes and chemistries. Even if finishers are strongly tied to existing equipment and treatment systems, surveys of metal finishers have demonstrated a "survivors will" to move into other markets. Exit barriers are also high as a result of potential site liability and cleanup costs—especially for any finishing facility that has been in existence for more than 15 years.

The competitive position of individual companies is likely to be influenced by the "supply" of firms in a given area and the relative amounts of "high-value-added" and "low-value-added" finishing performed.

As discussed in chapter 1, the general competitive position of low-value-added firms is often poor for several reasons: price competition, little customer loyalty, precarious

TABLE 13. Organizational Readiness Requirements for Utilities

Requirements for Service Offering Success	Organizational Competencies	Organizational Resources
Integrated marketing capability: The ability to manage information about customers and to communicate directly or indirectly with them through face-to-face, phone, electronic, or direct mail communications	• Ability to manage an integrated marketing effort; to coordinate multiple marketing activities at individual accounts • Ability to design and package the product/service offerings for specific customers Score: __________	• Marketing database of customers and contacts • Telemarketing and direct mail organization (internal or external) to manage customer contacts • Face-to-face sales organization consisting of people who go out and meet customers as necessary • Marketing communications group (internal or external) that puts together "customer offerings" and communications materials Score: __________
Market research about customer needs and perceptions: Determining what customers value and how that translates into products and services	• Effective product/service development group Score: __________	• Staff with marketing experience who have worked in other industries with demanding product development time lines Score: __________
Products/services to offer: Entry-level products might include power quality services, energy services, financing services, and/or technology evaluation services	• These services must be ready to go in some basic form; their sophistication may grow over time, but they must meet customer needs Score: __________	• Presale, transaction, and post-sale customer support for each product or service • A training function to train customers and staff • Technical support to help customers use the product and solve problems • Logistics support that gets the product and invoice to the customer in a timely manner Score: __________
"World-class customer service": The ability to answer customers' calls quickly and respond to their needs	• Customer service organization and processes that rival any consumer products company Score: _________	• Customer service group and management • Training • Field resources to solve problems • Root-cause analysis capability Score: __________
Streamlined decision making: The ability to modify service offerings quickly to respond to customer needs and competition	• Short lines of communication Score: __________	• Few levels of decision making • Ultimate decision-making authority vested in a manager who is "close to the customers" Score: __________
		Company Total Score: _________

Source: QDI Strategies, Inc.

profitability history, and susceptibility to losing business to overseas manufacturing.

High-value-added finishing features one or more characteristics that make the activity less of a commodity service. The competitive and financial position of finishers with more business in this segment is generally more positive because specialty, high-quality finishing (mostly plating work, rather than painting/coating) provides some differentiation of services; engenders closer, more long-term, and supportive relationships with customers; and can attract orders from manufacturers outside an immediate area.

A metal finishing business's viability is readily assessed in terms of four principal discriminants: exposure to international competition, displacement by alternative methods or materials, relative proportion of high-/low-value-added finishing, and vulnerability to environmental pressures. A firm affected strongly by one or more of these discriminants has a diminished likelihood of long-term survival.

Table 14 depicts these four discriminants and provides related questions (and scores) for evaluating a metal finishing company's business viability.

BLE 14. Assess ong- vel 1)

Discriminants	Questions	Possible Scores		Compa-nyScore
Exposure to international competition	Have you lost sales to metal finishers in Mexico?	Yes = No =	5 0	
Competition from alternative methods	Could mechanical finishing be used to coat any products you currently plate?	Yes = No =	10 0	
	Could powder coating be used to coat any products you currently paint?	Yes = No =	10 0	
Relative proportion of high-/low-value-added	Is the majority of your finishing highly specialized, with strict quality control requirements?	Yes = No =	10 0	
Environmental pressure	Do you have or need an air permit?	Yes = No =	10 0	
	Have your costs to sewer water increased the last two years, or are those costs about to increase?	Yes = No =	10 0	
	What are your environmental costs as a % of sales? (treatment, disposal, labor, administration)	< 0.1% = 0.1–0.3% = 0.3–0.7% = 0.7–1.7% = 1.7–3.0% = > 3.0% =	0 1 4 6 8 10	
		Total Score:		
	Rank for Level One	Long-term survival difficult		≥ 45
		Pass to Level Two		< 45

Competition from the International Metal Finishing Industry

Around the world, metal finishing firms provide essential services to a country's manufacturing base. The particular types of metal finishing conducted in a country are often intimately connected to the cornerstone export of that country. For example, Thailand boasts significant chrome finishing capacity to finish rolls used in textile production, while the small oil-exporting country of Bahrain has an extensive hard chrome finishing capacity—to plate gears, pumps, and other equipment used in oil extraction.

Besides serving a critical manufacturing infrastructure role, metal finishing is well suited to growth strategies in developing countries, given its often labor intensive nature and comparatively low technology and skill requirements. Development funds from organizations such as the World Bank, U.S. Agency for International Development, and the United Nations have been applied to technology transfer and assistance efforts targeting metal finishing operations in countries such as Sri Lanka, Pakistan, Malaysia, Indonesia, and Chile. Moreover, as multinational manufacturers choose to move fabrication and manufacturing operations offshore to take advantage of cheaper labor, metal finishing follows. Companies in these countries often feature a winning combination of 1990s process technologies and developing country wage structures. The net result has been an explosive growth in metal products manufacturing and finishing in developing countries over the last decade—especially among products that feature high-volume but simple finishes (i.e., low-value-added finishing). In 1992, exports of this type of commodity metal product from developing Asian countries equaled similar exports from the United States and Japan combined.

A comparison of two facilities, one in the eastern United States and the other in Tunisia, illustrates the similarities and differences between domestic and foreign finishing establishments. At one level, these facilities share much in common. Both are job shops specializing in copper/nickel/chrome processes on parts with complex geometries. The U.S. facility has annual sales of approximately $5 million; the Tunisian facility has annual sales of approximately $1.5 million U.S. dollars. Both facilities are experiencing sales growth of 10% annually and are in the process of expanding their finishing capacity. Both also market to highly demanding customers that expect superior quality. The age of their process equipment is identical, and both use untrained labor for parts racking and maintenance work.

Some notable differences nevertheless exist in the operational and competitive context. The U.S. facility's market is largely comprised of manufacturers located within a 150-mile radius. The Tunisian facility serves manufacturing facilities all over the Middle East. The U.S. facility has a longer operational history and a dedicated professional staff for process engineering and process bath control; the Tunisian facility relies heavily on international suppliers for these capabilities, as well as for troubleshooting and assistance on running parts. The U.S. establishment has line managers for each individual plating process. In contrast, the Tunisian facility has one plant manager who monitors all plating operations. Casting rejects are landfilled in the United States, whereas the significantly higher cost of raw materials in Tunisia demands that rejects go back into the casting pot. Finally, and perhaps most significantly, the U.S. facility has a long and strong family history, imposing a deeply embedded culture about how things are and should be done. The newer Tunisian establishment is run by professional managers with an extremely strong orientation to the bottom line and little personal attachment to anything but the business itself. These managers are fearless about undertaking technology and operational changes that meet their quality and cost criteria.

These contrasts are quite common when comparing facilities in the United States (and other developed countries) with those in developing countries. In many cases, foreign facilities constitute indirect competition for U.S. firms, since multinational original equipment manufacturers (OEMs) tend to buy metal finishing locally. For example, Whirlpool and Electrolux buy metal finishing for their Michigan plants in Michigan, and for their Malaysian plants in Malaysia. To the extent that OEMs expand offshore, U.S. firms will lose business.

Direct competition from international metal finishing facilities seems to be largely limited to firms in Mexico, mostly due to trade shifts encouraged and supported by the North American Free Trade Agreement (NAFTA). Starting with OEMs expanding in Mexico and purchasing metal finishing locally, the trend has expanded and accelerated to constitute direct competition for larger job shops nationwide, at least in a growing number of low-value-added finishes.

The longevity of the "NAFTA effect" is unknown. The view expressed by a plating facility manager in El Paso, Texas, whose firm specializes in automated barrel plating of copper, tin, and nickel for industrial markets, is that the potential loss of business due to discrepancies in environmental regulations is less a threat than first expected. According to this source, a current lack of regulatory enforcement and lower labor costs might move some finishing business across the border; however, these comparative cost disadvantages are more than offset by several competitive factors favoring U.S.-based operations. These include lower cost of chemical inputs, infrastructure support such as assurance of electricity for operations, quality of water inputs (essential to low-reject plating and lower operating costs), and capital availability. Moreover, the facility manager believed that any environmental advantage is likely to cease over the next two years as Mexican government enforcement activities accelerate and force Mexican companies to invest in the same environmental systems and controls U.S. firms already have in place. Some competitive advantage is likely to remain with Mexican facilities doing plating operations, which are very labor-intensive.

Competing Technologies that Replace Metal Finishing

Metal finishing is in competition with no single technology. The area of technology change that most seems to threaten the long-term health and welfare of the metal finishing industry is alternative substrates. For example, automotive manufacturers are currently leaning toward fabricated parts made of plastics rather than steel, hence reducing metal finishing requirements. Even though job shops may benefit some as manufacturers look to contract out their remaining metal finishing needs, the net effect is a loss of metal finishing business. Other technology developments in engineered plastics, ceramics, and alloys may reduce the need for metal finishing in additional markets. Indeed, with advances in primary metals manufacturing, desirable finish qualities are being directly engineered into metals.

These marketplace changes suggest several options for technology investments that can help metal finishing firms adjust and thrive. Any firm that is not following up on these trends, where appropriate, is clearly less viable.

Short-Range Trend: Growth of Powder Coating. Powder coating has made major inroads into liquid coating markets and penetrated traditional decorative plating markets as well. Its popularity is likely to continue to increase for years to come. Advances in powder technology and delivery systems continue to open up new applications. The desirability of powder coating is based on the near elimination of water wastestreams and air emissions, as well as superior materials-use efficiency. Industry experts believe that new finishing capacity currently being built or planned for the future will almost certainly provide for powder coating (see also pp. 26, 36–37).

Medium-Range Trend: Expansion of Physical and Chemical Vapor Deposition. Like powder coating for the painting sector, vapor deposition technologies are "dry" finishing processes for metal plating. Several technologies are currently available to transport metals in a vapor state to a part to achieve a solid metal coating. Currently limited to very specific, often high-end applications, advances in vapor deposition technologies to accommodate larger parts and higher production rates hold the promise for a substantial reduction in water wastestreams in these operations and wider adoption of vapor deposition techniques (see also pp. 32–33, 40–41).

Long-Range Trend: Next-Generation Technologies. Advances in materials science now hold the promise of radical changes in the way metal parts are finished and/or a reduction in the need for finishing through alternative substrates, as mentioned earlier. Three classes of technologies (in addition to new substrates) are now undergoing investigation at the laboratory level:

- Nonaqueous liquid baths—processes that rely on materials other than water (such as alcohols) for the matrix
- Advanced physical bonding—processes that deposit metals through physical rather than electrochemical contact
- "Nanotechnologies"—advancements in laser technology that would finish parts by placing metal ions onto substrates

Environmental Pressures

The metal finishing industry is second only to the nuclear industry in terms of the number of applicable environmental regulations and reporting requirements. As mentioned earlier, the EPA regulates 46 different metal finishing processes. Since metal finishing processes generate pollutants and emissions specific to each process, environmental pressures vary from firm to firm.

According to industry experts, many metal finishers estimate their environmental management costs at 10–14% of sales, but benchmark studies suggest that costs are actually closer to 3% of sales overall (similar to the SFMRB survey results). This discrepancy suggests metal finishers' high degree of concern about runaway compliance costs. The management of water use and release is the primary issue and the focus for most innovation at metal finishing facilities. In a 1993 survey of metal finishers, reported in *Plating and Surface Finishing* magazine, 89% of respondents identified wastewater discharge as their primary environmental management problem. Overall, 62% of annual plating industry environmental management operating cost expenditures and annual pollution abatement capital expenditures were directed toward water media protection.

A 1994 survey by the National Center for Manufacturing Sciences (NCMS) found that the average capital cost of a facility wastewater treatment system is over $250,000. Annual operating costs depend on the sophistication of the system, flow rates, and concentration of pollutants entering the system, but are comprised of three major elements: labor, treatment chemicals, and sludge disposal. Of these, chemical costs is the largest. The cost of treatment chemicals in plating facilities can be over half the annual operating costs for a wastewater treatment system, and the total annual operating cost of a wastewater treatment system is frequently 50% or more of the original capital cost of the system.

Plating and coating operations share many of the same regulatory pressures. Plating facilities, however, have greater concerns for wastewater discharges and related controls, whereas most coating operations have higher volumes of air releases and therefore more exposure to air pollution control regulations.

Wastewater Discharges. Water and wastewater issues are the largest and fastest-growing environmental concerns for metal finishers. Any firm located in a district experiencing chronic water supply shortfalls, or discharging to a POTW that itself discharges treated effluent to sensitive bodies of water, is or soon will be under tremendous pressure to make major modifications to its processes, or exit the business.

Land Disposal. Treatment and disposal of solid hazardous wastes is subsiding as an issue. Not only does excess treatment and disposal capacity exist around the country, driving down prices, but the regulations themselves are being interpreted somewhat differently, allowing and even encouraging recycling and reuse of these sludges. This leads to a reduction in cost pressures and liability concerns, and means that firms are less motivated to undertake process improvements that reduce solid waste generation. Firms with significant hazardous waste concerns are those with high percentages of cyanide in their sludges, or mixtures of heavy metals that make sludge recycling difficult.

Air Releases. The issues affecting a facility's air regulation profile include the amount of emissions, type of processes, size of operation, and whether the operation is new or existing. Applying for a permit can cost a facility $15,000 to $30,000 in necessary assessment and consulting fees. While not a regulation, the Montreal Protocol increases pressure to reduce or eliminate solvent cleaning by restricting the production and use of ozone-depleting chemicals. The ozone-depleting substances currently used as solvents are targeted for complete elimination.

Other Regulations. Plating operations are subject to several other regulatory burdens as a result of the amount of hazardous materials used in and resulting from their processes. “Right to Know” laws, which involve public reporting on uses and releases of toxic chemicals, may apply to larger facilities. Superfund liability is a particular issue of concern—especially for older plating operations—since a facility is liable for any site contamination, even if it occurred as a result of practices prior to promulgation of the regulation, and/or as a result of practices of a former business owner. OSHA laws also have substantial impact on finishing operations because of the potentially hazardous work environment. General management and reporting requirements add to the labor cost burden for finishing operations.

In general, older facilities have greater difficulty improving their work environment to enhance worker health and safety. The age of the physical plant and the age of the capital equipment contribute to this difficulty. Firms that have low-value-added finishes as part of their service offering tend to have older facilities and equipment; hence, regulatory pressures have a very strong negative effect on their viability.

LEVEL 2 ANALYSIS: Products and Processes for Which Process Improvement Is Considered Timely

Firms that "pass" the first level of screening are more likely than others to be viable for the foreseeable future. Of these firms, those surviving the Level 2 analysis are more likely to have process improvement opportunities that are well-supported in the literature and in practice. This type of opportunity is more likely to be seen by metal finishers as a "safe" process change, one they might be receptive to undertaking.

Understanding process improvement opportunities requires some knowledge of typical process steps, which were explained in more detail in chapter 2. This section briefly reviews key process steps and suggests technology options (also see appendix A, Technology Profiles). It presents "technology mixes" that define "low-end," "standard," and "best-in-practice" applications of technology. Two cautions about these mix profiles: first, the economic and environmental logic of implementing various techniques and technologies is extremely case-specific. A facility may have a number of legitimate production, economic, and technical reasons for not employing a technique or technology that, independent of that context, could be labeled a "process improvement." Second, best-in-practice mix profiles assume the availability of capital funds and shop floor space.

Table 15 gives a sample of discriminating questions and scores for evaluating a firm's readiness for process improvement changes. In addition to use in Level 2 screening, this "timeliness score" links with table 17 (see p. 61), which identifies specific process improvement opportunities and energy supplier assistance options. Note that in some categories, high scores are given at both ends of a range. These scores reflect, at one extreme, a system in need of a major overhaul rather than just fine-tuning assistance; at the other, a system already employing advanced processes such that no further assistance would be warranted.

Metal Cleaning/Surface Preparation

Two primary types of cleaning approaches are found in metal finishing operations: solvent-based systems and aqueous systems. Because of regulatory phaseouts and air pollution concerns, the use of halogenated solvent cleaners is on the decline, although a number of nonhalogenated solvents are used as alternatives. Aqueous systems are a popular alternative to traditional solvents; they use alkaline cleaners. The choice of cleaning technology is driven by both the type of production (intermittent vs. continuous high production) and the type of cleaning required (oil and grease, metal chips and cutting fluid, polishing compounds, etc.).

Technology Mixes for Cleaning. A low-end technology mix for parts cleaning might include a heavy reliance on chlorinated solvents. Cleaning would be accomplished through hand wipe, cold cleaner application, or vapor degreasing (with no solvent emission controls) in open buckets or tanks. Organic solvent would be present in wastewater as the result of spills or drips. No solvent recovery would be attempted.

TABLE 15. Assessing a Firm's Likelihood for Process Improvements (Level 2)

Process Area	Questions	Timeliness Scores		Company Score
Metal cleaning/ surface preparation	How many gallons of solvent does your facility use per $100,000 of finishing sales?	< 10 gal =	0	
		10–100 gal =	1	
		100–600 gal =	4	
		600–2700 gal =	6	
		2700–5400 gal =	8	
		> 5400 gal =	10	
	How much do you spend on cleaning chemistry as a % of all process chemistry purchased?	< 0.5% =	0	
		0.5–1.5% =	1	
		1.5–2.5% =	4	
		2.5–3.5% =	6	
		3.5–4.5% =	8	
		> 4.5% =	10	
Finishing processes: plating/coating (choose one)	How much of the metal purchased for plating solutions becomes plating on parts?	> 95% =	10	
		85–95% =	8	
		80–85% =	6	
		70–80% =	7	
		60–70% =	8	
	(OR)	< 70% =	10	
	How much of the paint (as solids) purchased becomes coating on parts?	> 90% =	10	
		80–90% =	8	
		40–80% =	6	
		30–40% =	7	
		20–30% =	8	
		< 20% =	10	
Waste handling processes	How many gallons of rinse water are used per $100,000 of finishing sales?	< 36,000 gal =	1	
		36,000–97,000 gal =	2	
		97,000–213,000 gal =	4	
		213,000–427,000 gal =	6	
		427,000–894,000 gal =	8	
		> 894,000 gal =	10	
Energy use	What are your energy costs as a % of sales?	< 2.1% =	0	
		2.1–3.2% =	2	
		3.2–5.4% =	4	
		5.4–6.7% =	6	
		6.7–9.4% =	8	
		> 9.4% =	10	
		Total Score:		
	Rank for Level Two	Processes at or near best-practice level		≤ 18
		Pass to Level Three		> 18

A standard technology mix would include use of alkaline-based aqueous systems. Nonchlorinated solvent alternatives would be used for spot cleaning. Vapor degreasing might be used for certain parts, although these activities would feature best practices to control emissions—such as increased freeboard, an automatic roll top, and a refrigeration zone to supplement conventional cooling.

A best-in-practice technology mix would eliminate chlorinated solvents from operations. Cleaning technologies are similar to the standard profile, with some operating differences. First, efforts would be made to understand specific soil types and their sources to identify source reduction options. For example, a low-end shop might assess an alternative solvent for the removal of polishing compounds as ineffective, and stop there. A "best-practice" shop would explore how the polishing technique itself can be changed to allow for alternative cleaning strategies. Second, a best-practice shop would make an effort to extend the life of "expendable" aqueous cleaning baths through process optimization using technologies such as oil skimming and microfiltration.

Finishing Process: Plating

The core plating process is a series of deposition and rinse steps to achieve the desired metal finish characteristics. Multiple depositions of different metals may be needed to achieve the desired end product. Plating process bath inputs depend on the type of plating and product specifications.

Process outputs from plating baths largely mirror the process inputs. Many factors cause process baths to breakdown after a period of time; these include: 1) chemical breakdown of process chemicals or side reactions; 2) contaminants entering the bath from makeup water or shop atmosphere; 3) corrosion of parts, racks, tanks, etc.; 4) parts dropped in tanks; and 5) dragin of noncompatible chemicals.

Technology Mixes for Plating. A low-end technology mix for the plating process would include one or more "first-tier" efforts to preserve bath lives through bath maintenance techniques. Filtration, carbon treatment, electrolysis, and batch precipitation of contaminants are common techniques employed by platers for decades. Among low-end shops there is little effort to understand when or why corrective solution maintenance activities such as filter changes are needed. Corrective treatments are initiated by "eyeballing" process solutions or only after part rejects begin to occur.

A standard technology mix would combine first-tier solution maintenance efforts with more sophisticated bath regeneration technologies. Efforts would be made to minimize waste resulting from the use of corrective technologies. These efforts might include the use of reusable filters and the development of standard operating procedures for filter changes so that reject parts are not the first prompt for corrective action.

A best-in-practice technology mix would emphasize careful monitoring and process control of bath chemistries to optimize performance of the bath itself as well as to regenerate bath process outputs.

Finishing Process: Painting/Coating

The concept of transfer efficiency is critical to improving productivity of the painting line and minimizing paint waste. For non-spray applications such as dipping, flow coating, or roll coating, transfer efficiencies are typically well above 90%. For spray systems, transfer efficiencies are typically lower and vary depending upon production factors including the type of spray equipment, geometry and size of part, operator practice, racking design/arrangement on conveyor, volume of solids in the coating, and air and fluid pressure. Poor process and operating control combined with difficult-to-paint parts can reduce transfer efficiencies to 5% or less.

The overspray in painting operations must be collected in the spray area to prevent release of paint particulate air emissions. Use of water wash booths results in a paint sludge, while dry filter booths produce paint waste in filter media. The volume of paint particulate emissions is a function of the transfer efficiency, the filter efficiency, the air velocity in the booth, and the weight solids of the coating. Production changes require flushing of paint lines and cleaning of paint equipment. Spent solvent and cleaning rags are another application process output.

Technology Mixes for Painting/Coating. As with other types of metal finishing operations, the specific needs of a facility and end product will largely determine the type of technologies implemented. These mix descriptions are only very general rules, since a number of site-specific production, quality, and performance considerations must be considered.

A low-end technology mix would feature the use of conventional air atomizing guns providing the lowest estimated transfer efficiency rates (25% or less). A number of operating practices lead to excessive paint waste, including excessive atomizing pressure causing particles to “bounce back” off the workpiece, poor gun triggering, and poor parts racking. Traditional solvent-borne coatings are used and ambient temperatures are permitted to vary, thus changing the viscosity of the paint and perhaps requiring additional solvent as a corrective measure. Inexpensive ($1), low-capacity (2 pound), nonreusable filters are used in the spray booths.

A standard technology mix might move away from conventional air guns and alternative coating technologies. Spray systems would include: HVLP guns; air-assisted airless and airless guns; and electrostatic guns. All of these systems have higher average transfer efficiency rates than can be achieved with conventional air atomizing guns. Low-VOC coatings, waterborne coatings, and high-solids coatings are substituted for traditional solvent-borne paints. Spray booths feature high-capacity, high-efficiency filters and/or reusable filter media to reduce hazardous waste generation. Recycling and recovery systems for solvents and paint booth water may be installed. Attention is paid to good operating practices and procedures to improve transfer efficiency and minimize waste.

A high-end technology mix might substitute thermoset powder coatings or ultra-low-VOC coatings (electrocoatings, UV curable coatings, polyurea) for traditional liquid coatings. Electrostatic equipment and robotics are extensively used to improve efficiency and control of paint application.

Waste Handling Process: Rinsing

As with the plating or coating process, rinsing is often a series of rinse steps to remove process solution and chemical agents. Water use and dragout minimization are the primary environmental issues of concern.

The first step in rinsing is often to immerse a part into a nonflowing or “dead rinse,” where the highest concentration of process solution dragout is removed. Following the dead rinse, the part may enter series of flow rinse tanks to further remove process chemistries. A common arrangement and description for these flow rinses is called countercurrent rinsing. Generally, the more countercurrent rinse tanks, the less total water used for rinsing.

Most material inputs in a flow rinsing process consist simply of water, although deionized water is preferable. Process outputs in rinsing consist of the potpourri of chemicals, metals, and agents contained in the process solution.

Technology Mixes for Rinsing. A rough but simple benchmark for the efficiency of all rinsing done in a plating process is calculated as a "total water flow-to-tank" ratio:

$$\frac{\text{total process water input to plating (gal/min)}}{\text{number of rinse tanks}}$$

A low-end technology mix would feature a total water-to-tank ratio greater than 5. Tap water is used in a two-stage critical rinsing process: a dead rinse followed by one flowing rinse. A main water valve turns on water to all rinse tanks. Rinse waters go directly to the pretreatment system prior to discharge.

A standard technology mix features countercurrent rinsing lines and a total water flow-to-tank ratio between 1 and 5. Typically, one or more of several chemical recovery and concentration technologies are employed on the rinse waters. Many waste reduction efforts may have been tried but abandoned for reasons such as "hassle" or lack of maintenance. For example, a standard firm may evaluate and perhaps (despite the expense) install conductivity cells to make sure water flows only when needed and only to a set value of contamination in the rinse tank. However, over time the cells become corroded and no longer close the water valve. Other "low-maintenance" efforts are implemented, such as improved rinsing procedures, by extending the contact time the part is actually in the rinse bath.

A best-in-practice mix features countercurrent rinsing, a water flow-to-tank ratio of less than 1, and a number of mostly low-cost techniques and technologies to minimize dragout and optimize rinsing effectiveness. Drain boards are in place to catch drips and return the plating solution back to the process tank. Drain times over process tanks are extended and parts are oriented on racks to minimize solution carry over into the rinse. Spray rinses and air knives are mounted on the process tank to knock process solution back into the plating tank before it can enter the rinse. Air agitation is also installed in the tank to improve rinsing efficiencies. Recovery and concentration technologies found in the standard technology profile are also likely to be used.

Energy Use

Among metal finishers, interest in scrutinizing energy costs has fluctuated, driven by the price of energy supplies. While many facilities have made changes such as installing high-efficiency light fixtures and ballasts, or reducing air compressor leaks, few have instituted any formal measures to control demand. In many shops, still, process tanks and piping remain uninsulated—despite data showing that 30% of the heating energy is lost due to evaporation. The increasingly common use of programmable logic controllers (PLCs) means more metal finishers are able to easily track their energy use, but use of the tracked data remains low. This may be due to the perception of energy simply being "a cost of doing business" rather than an opportunity for optimization boosting a shop's competitive advantage.

Technology Mixes for Energy Use. A low-end technology mix would feature large numbers of cleaners operating at temperatures above 140°F; no provisions for control of evaporative heat losses through insulation of tanks or process piping; a lack of temperature controllers for high-temperature applications; and large numbers of motors running continuously even when not in use.

A standard technology mix features some level of energy conservation measures; for example, high-efficiency relamping of all fluorescent and related modification of fixtures; insulation of process equipment and/or covering tanks when not in use; operation of motors and (sometimes) lights using demand switches.

A best-in-practice mix features formal tracking of energy use by machine and/or activity, often linked to PLCs but sometimes maintained as a separate activity, with scheduled reviews and opportunity analysis. Heat recovery (exhaust, stack, hot water) is in place, as well as a facilitywide peak demand control system. High-efficiency motors are installed to replace worn out ones, and variable-speed drives are used wherever appropriate.

LEVEL 3 ANALYSIS: Firm-Level Indicators of Process Improvement Success

Firms that pass the second level of analysis are likely to have well-respected process improvement opportunities. Even well-qualified process improvements are not automatic candidates for implementation, though, because each firm has very specific realities that affect process change. To the extent that the following firm-level "indicators of success" can be discovered in advance, energy suppliers can better target outreach activities to the firms best able and most likely to move ahead with recommendations.

One of the principles of manufacturing excellence is to reduce cycle times—the total processing time needed to manufacture a part. Metal finishers, like other manufacturers, look for ways to reduce their processing times while maintaining high quality, thereby enhancing productivity. A critical issue in many finishing operations is that (quality issues aside) the adoption of many environmentally preferable technologies and practices may often increase processing times, sometimes substantially. Productivity and pollution prevention are at potential loggerheads in many metal finishing situations. In addition, productivity and output in metal finishing operations are influenced by a number of production parameters. The following firm-level variables are especially influential in plating productivity, and will influence greatly the types and extent of process improvements considered feasible by a firm.

Table 16 provides questions and scores for evaluating a firm's likelihood of successfully embracing process improvements.

Product-Related Variables

Parts Geometry. Both the shape and size of the parts finished influence manufacturing throughput. Larger workpieces and pieces with complex geometries typically take longer to finish than smaller workpieces or parts with simple geometries. Moreover, larger complex pieces typically must be rack-finished. For plated finishes, smaller, simpler pieces can be batch processed through barrel plating. Large, complex parts also have process waste and environmental implications because they are generally more difficult to rinse, thus requiring more water and time to achieve the desired cleanliness.

Specifications. Coating thickness, corrosion resistance, brightness, and color are quality factors stipulated in metal finishing specifications. The manufacturing specifications and the process steps needed to accomplish them affect manufacturing throughput. Inspection for thickness is especially problematic since real-time (in-

TABLE 16. Assessing a Firm's Likelihood of Implementing Process Changes (Level 3)

Discriminants	Questions	Possible Scores		Company Score
Product-related variables	What is your value-added per shop employee? (finishing sales ÷ # shop employees)	> $125,000 =	8	
		$88,000–$125,000 =	6	
		$67,000–$88,000 =	2	
		$49,000–$67,000 =	0	
		< $49,000 =	10	
	What are the most common specifications for the finishing you perform?	Performance or open specs. =	2	
		Process specs. =	10	
	What percentage of your production is parts that require more than one shift to process and are processed at least four times per year?	100% =	9	
		80–100% =	8	
		50–80% =	6	
		30–50% =	0	
		< 30% =	10	
Process-related variables	What percentage of your production is processed using automated equipment?	100% =	10	
		70–100% =	9	
		30–70% =	6	
		< 30% =	0	
	How old is your physical plant?	< 10 yr =	10	
		10–20 yr =	5	
		> 20 yr =	0	
	What percentage of your production equipment has an age of 2–10 yr?	100% =	0	
		75–100% =	5	
		25–75% =	10	
		< 25% =	0	
Management variables	What percentage of total production is scrapped or reworked before shipment? (internal rejects)	< 0.35% =	10	
		0.35–1.0% =	8	
		1–3% =	6	
		3–5% =	4	
		> 5% =	0	
	Is your facility a captive operation or a job shop?	Captive =	10	
		Job shop =	0	
	Have you implemented waste reduction or energy saving practices in the last five years?	Yes =	10	
		No =	0	
		Total Score:		
	Rank for Level Three	Implementation Success Not Likely =		≤ 55
		Implementation Success More Likely =		> 55

process) inspection requires the finisher to stop the line, clean and/or dry the part, check for thickness, make adjustments, and restart the process.

Masking or Plugging. Productivity is also affected by the amount of masking or plugging a part requires. In a growing number of finishing applications, only a portion of a part may need coating. Masking and plugging prevents coating inappropriate areas of the workpiece, but also slows throughput rates.

Single-Load versus Long Runs. The need to change processes frequently to accommodate different jobs reduces manufacturing throughput when compared to the ability to run a particular piece or group of pieces needing the same finishing process for extended periods.

Unfamiliar Parts. Although production specifications often provide guidance on running parts, a significant element of “art” and experience is involved because of the chemistry and physics of the processes. Familiarity and experience with certain process chemistries, achieving particular production specifications, or similar work-piece geometries all benefit an organization from the standpoint of productivity and throughput.

Process/Product Mix. In a survey of metal finishers conducted by the SFMRB in 1992–93, the participating facilities averaged 2.2 plating lines per shop. Steel substrates constituted the majority of the surface area being finished (68.2%), followed by copper and its alloys (brass, bronze, etc.), aluminum, and zinc. Average facility plating volume was reported as 2 million square feet per year. In general, metal finishers are tending to perform fewer finishes, but to do those extremely well and efficiently.

Process-Related Variables

Level of Automation. Facilities with high levels of automation are more amenable to process improvement in many regards. In the first place, facilities with the capital and technical expertise to specify and operate automated equipment often are more flexible financially and have more competent staff, two key components in process improvement. In addition, the equipment itself is often operated at high production volumes, which means that any savings multiply quickly. Finally, manual operations are often very difficult to modify successfully because of the human factors involved. To the extent that a modification relies on written procedures and human activities, it is more likely to fail.

Age of Physical Plant and Equipment. Old facilities with old equipment often indicate a commune in difficulty of some sort, which is itself an implementation challenge. In cases where a turnaround is being planned, the difficulty shifts to the size of the task and associated time constraints. If process improvement is taking place as part of a general upgrade, implementation success is likely, and depends mostly on introducing new information at the correct time. If process improvement is leading the upgrade, many times good ideas will fall by the wayside for lack of analysis in the rush to completion. If process improvement is piecemeal, changing old equipment here and there and fighting against an outdated physical plant, the challenges may be too great for success.

Management Variables

Employment. Workforce skills vary substantially in metal finishing shops, generally in keeping with the type of metal finishing performed. On one end of the finishing spectrum, low-value-added plating of simple parts can require little in the way of skilled labor. On the other end, expensive intricate parts, precious metal plating, and/or plating to tight specifications will likely require a skilled labor force intimately familiar with total quality management tools and statistical process control. Experienced platers and, to a lesser extent, painter/coaters are highly valued for the knowledge they accumulate over time.

Sales and Profits. Industry surveys and other business data suggest that most U.S. metal finishing facilities have an annual sales volume of $1–$3 million. According to

Dun and Bradstreet data for 1993, net profits are about 5% of sales, and finishing capacity is not necessarily positively correlated to greater profitability. For example, in the plating sector in 1993, establishments with assets under $250,000 reported a better return on assets and profits as a percentage of sales than did facilities with assets over $1 million. The same appears true for painters/coaters: the smaller facilities have some of the best profitability ratios and financial returns. Experts suggest this relationship exists because the highly capitalized shops compete in high-volume finishing markets that are more competitive and, as a result, feature lower margins. In turn, lower capitalized shops are more likely to be specialty platers and may feature higher margins.

Capital Availability. The availability of capital is an ongoing issue for many metal finishing firms. According to U.S. Dept. of Commerce data, total capital expenditures in 1992 averaged $53,878 for firms in SIC 3471 (plating and related) and $65,496 for firms in SIC 3479 (painting and coating). Although varying degrees of capitalization are needed to compete in different finishing markets and comply with regulations, the purchase of a major piece of equipment is often equal to or greater than the entire net profit of a facility for a given year.

Supplier Relationships. The relationship between finishers and their suppliers is a key factor affecting environmental and business performance of the industry. In addition to equipment and materials sales, vendors provide a variety of other support activities, including technical support for troubleshooting and engineering, process design assistance, and financial support (such as covering switching costs for process chemistry changes). Finishers rely heavily on suppliers for information on technology availability and proper operating practices. The growing sophistication of process chemistries and equipment (largely as a function of environmental concerns), is expected to increase this dependency.

Captive versus Job Shop Operation. Process improvement decisions are made and supported differently in job shops as compared to captive operations. A decision on whether finishing should be done in a captive environment or contracted to a job shop is based on a number of business, production, and economic factors, as discussed in chapter 1.

Industry professionals see a trend toward outsourcing more metal finishing activities to job shop operations. This may be evident already in the growth of the number of enterprises performing coating and related finishing. Although environmental compliance issues and costs are undoubtedly a driver for outsourcing, for many firms it may be a secondary issue to mainstream manufacturing and production changes.

PROCESS IMPROVEMENT OPPORTUNITIES

Having used tables 14–16 (or some region-appropriate variation) to evaluate metal finishing companies and determine those most ready and able to implement changes, the next consideration is to identify appropriate process improvements to recommend to metal finishing customers. There are three key classes of process improvement: process control and operating practices, chemical recovery technologies, and process chemistry and equipment substitutions. All of the opportunities available in these areas have been extensively profiled in pollution prevention guides, metal finishing manuals, and engineering handbooks (see appendix D, Resources). However, only the best-in-practice facilities have adopted them. The con-

TABLE 17. Process Improvement Opportunities

Operation or Use	Timeliness Score	Process Improvement Opportunities	Effects on the Facility *Impact on Energy Use*	Assistance Needed
Metal cleaning/surface preparation	4–10 (solvent use)	Process substitution: switch to aqueous cleaning	Improved environmental performance *Increased need for drying* *Increased evaporative losses of heat*	Engineering support Options research Pilot studies
	2–10 (cleaner use)	Optimize use of cleaners	Reduced raw material costs Quality improvement *N/A*	Activity-Based Costing (ABC) or similar allocation to determine benefits
Finishing process: plating	7–10	Reduce dragout	Reduced raw material costs *N/A*	ABC Engineering support
		Recover dragout	Reduced environmental management costs *Increased energy use to concentrate process chemistry from wastewater*	Options research Pilot studies
		Improve process controls	Improved quality Improved throughput *N/A*	ABC Support in developing systems for quality control/quality assurance (QC/QA)
Finishing process: coating	7–10	Optimize application practices Optimize application equipment	Improved environmental performance Reduced raw materials costs *Increased need for drying/baking (for water-borne and powder coating)*	Options research Pilot studies
		Change coating type to water-borne or high-solids	Improved environmental performance Reduced raw material costs (for powder coating) *Increased need for drying*	Options research Pilot studies Improved quality
		Improve process controls	Improved throughput *N/A*	ABC Support in developing systems for QC/QA Pilot studies
Waste handling process: rinsing	2–10 (high-value-added) 6–10 (low-value-added)	Improve rinsing efficiency and effectiveness; complete dragout reduction first	Reduced raw material costs Reduced environmental management costs Improved quality *N/A*	Energy use tracking Engineering support
Energy use	4–10	Reduce/recover heat losses Reduce peak loads	Reduced input costs Energy conservation Reduced input costs *Energy conservation*	Energy use tracking Engineering support
		Improve energy efficiency of equipment	Reduced input costs *Energy conservation*	Energy use tracking Engineering support

sensus among industry experts is that many metal finishing facilities would embrace these opportunities to improve their competitiveness, productivity, and environmental control—if they had some support.

Table 17 lists 11 types of opportunities that experience shows metal finishers will adopt when certain kinds of assistance are available. Facilities in the “yes” category following analysis Level 3 can be further considered for services using their “timeliness score” (table 15) and the opportunities presented in table 17 (grouped by process, per table 15). Note that the list of opportunities is intentionally short. There are many more options for process improvement, but they are more complex—best considered after these simpler options have been implemented and successes have begun to appear.

The emphasis on the environmental compliance aspects of this select list of recommended process improvements is intentional. Metal finishers view productivity and competitiveness issues as the province of process experts, not energy suppliers. Gaining their trust and learning their business by linking improvement options with the environment will help overcome this roadblock. Pollution control requirements are the only drivers that metal finishers fear and do not understand. Even though environmental issues are not named as a key driver, once an energy supplier associates an environmental compliance change with cost reduction and/or productivity, the motivation for implementation gains new force.

Alternative Process Chemistries and Equipment

Innovations are occuring in the development of new, environmentally preferable process chemistries. Many of the innovations involve reformulation of existing process solutions to lengthen their useful life, make rinse waters easier to treat, or otherwise reduce their potential environmental impact (e.g., low-cyanide chemistries). At the other end of the innovation spectrum is the development of new process chemistries to meet one or more finishing requirements. Three particular materials used in plating—cyanide, cadmium, and chrome—have been the focus for most chemical substitution efforts because of strong regulatory drivers.

The success of process substitutions is mixed because of the application- and use-specific nature of finishing. In certain applications, process substitutions have proven to be cost-effective strategies and occasionally have improved quality. Substitution of trivalent chrome for the more hazardous hexavalent chrome in decorative finishes, and zinc chloride in place of zinc cyanide chemistries, are two of the most notable success stories. These, however, are exceptions rather than the rule. In most cases, a potential substitute process will entail some performance trade-off or qualification that may prevent its use. There are few, if any, direct chemistry substitutions; that is, a substitute process may achieve 95% of the performance qualities desired, but the absent 5% may make the alternative totally infeasible or jeopardize quality. Even if the alternative is technically feasible, the substitution may fail from a production or economic standpoint. Alternatives may be prohibitively expensive, require more time to plate the part, or require a level of process control outside the capabilities of the facility.

Of all the areas of innovation, material substitution is the most fraught with implementation barriers since the status quo is nearly codified, either informally through customer acceptance and existing investments in recovery and concentration technologies, or formally through customer specifications that demand the use of specific materials. The status quo is best overcome when regulatory drivers are pointing toward a complete "sunsetting" of materials of concern.

Switch to Aqueous Cleaning. In response to concerns arising from solvent-based cleaning and degreasing operations, a variety of aqueous and semi-aqueous cleaning systems have been developed. These systems most commonly use alkaline cleaners to remove the materials and soils. The appropriate technology choice is a function of the type of production (intermittent vs. continuous high production), and the type of cleaning concern (oil and grease, metal chips and cutting fluid, polishing compounds, etc.) Additional technology developments include microfiltration equipment to regenerate and extend the lives of aqueous cleaning baths. For further information, see the Aqueous and Semi-Aqueous Cleaner technology profile in appendix A.

Change Coatings. A transition to high-solids coatings from conventional coatings is often a first-level strategy for air emissions reductions. Unlike conventional coatings, which are typically only 30% solids, high-solids feature substantially reduced solvent content and are up to 80% solids. New technology developments and delivery systems have overcome many of the performance and application problems that initially plagued high-solids implementation. Key questions to be asked in evaluating high-solids coatings are

- Can existing spray equipment properly atomize the paint?
- Will paint heaters be required to provide proper viscosity?
- How will potentially longer drying times affect production schedules?
- Does an oven need to be installed?
- Will the coating require more diligent surface preparation?
- What film thickness differentials can be expected? Will color and gloss patches result?
- Will changes need to be made to spray booth design/airflow, etc.?

Waterborne coatings use water instead of organic solvents for the solvent component of the coating, although most waterborne coatings have some VOCs or HAPs. As with high-solids paints, ongoing technology developments of waterborne coatings have extended their applications into a number of high-performance areas. Most any type of application technique can be used on waterborne coatings. The primary cost savings stem from reduced cleanup expense and reduced insurance premiums. The primary disadvantages often include a slower dry time and more potential for film defects without careful pretreatment operations. In the past, waterbornes received the reputation of being inferior to solvent-borne coatings for several performance characteristics. Although technological advancements have not yet overcome this perceptual hurdle, they are likely to make waterbornes the choice with the broadest potential for application. Key questions to be asked in evaluating waterborne applicability are

- Is the current surface preparation adequate?
- Do drying time differences require installation of an oven?
- Can the same coating application equipment be used?
- What modifications will need to be made to electrostatic systems to accommodate a waterborne coating?
- Will it be compatible with existing water wash spray booths? Will it cause foaming?
- What learning curves exist for the operator to apply the coating successfully?

Compared to liquid coating systems, powder coatings provide significantly better environmental performance. No solvents are used in the mixing, application, or cleaning of powder systems, and the resins themselves average around 1% volume VOC content. Paint waste is minimized through electrostatic delivery, and the recycling capabilities of most powder systems provide material application efficiency rates of over 90%. Most powders are classified as nonhazardous, and energy requirements may be lower for two primary reasons. First, VOC-free powder booth exhaust air can be recirculated to the plant, eliminating the cost of heating or cooling makeup air. Second, ovens that cure solvent coatings must heat and exhaust large amounts of air to ensure solvent fumes do not reach dangerous limits. Required exhaust flow for powder is substantially lower.

As can be expected, despite the clear superiority of powder coating from an environmental standpoint, a number of production issues must be carefully considered and may limit its application. Key questions to be considered are

- Is current surface preparation of substrate adequate for powder coating?
- What new equipment will be required by way of booths, guns, and electronic controls?
- Will a new oven be needed?
- Will powder coating provide a finish that will satisfy customer expectations?
- How will reject parts be dealt with?
- Does the geometry and configuration of the parts lend themselves to powder application?
- Are length of production runs compatible with powder application?

Ultra-low/no-VOC coatings have been developed for specialty applications. Autophoretic coatings are dip-based coatings for steel substrates, typically used as an intermediate coat. They are especially suitable for large-volume coating operations with limited workpiece configurations. Electrocoatings (which operate like electroplating baths) feature low VOCs, comparatively low hazardous waste, and low water pollution when properly operated, and are used for coating steel and aluminum substrates. They are also intended for high-volume captive operations. These alternatives hold promise for specific applications although capital, space, process control, and other cost considerations may limit broad acceptance and implementation.

Optimize Coating Application Equipment. To improve transfer efficiency and reduce paint waste, many facilities may switch to alternative application technologies. Alternatives to conventional spray systems abound and each have their own unique performance and production considerations that need to be evaluated (see pp. 34–37). Nonspray systems such as dip coating, roll coating, or curtain coating have significantly higher transfer efficiencies, although their ability to be used on traditionally sprayed parts is limited. Although transfer efficiencies estimates have been generated by the EPA and other organizations, they should be used with caution since operator practice, maintenance, and other site-specific production factors will ultimately determine the efficiency of a painting line. Nevertheless, these numbers are a useful reference.

OSHA guns may be the most flexible of the conventional spray alternatives since they can be used for quality or functional finishes, can coat intricate parts as well as those with simple geometries, and can be used with higher solids and waterborne coatings. The primary disadvantages are the relative newness of the technology and the operator training requirements. No EPA transfer efficiency estimate exists although ranges of 50–90% have been reported.

Airless guns atomize paint through application of extremely high hydraulic pressures. Airless guns are especially good alternatives for high-viscosity coatings and for painting large, uncomplicated surfaces. High-pressure coatings in airless systems also pose a significant worker safety risk. EPA estimated transfer efficiency: 40%.

Air-assisted airless spray guns reduce necessary fluid pressures by 50% or more. Air-assisted airless is still largely limited to applications that do not need fine finishes. EPA estimated transfer efficiency: 40%.

Electrostatic guns can be conventional, airless, or air-assisted airless guns. The attraction between the charged paint particles and the workpiece substantially improves paint transfer efficiencies and reduces paint waste and cleanup. There are significant startup costs, however: a single gun may cost $3000 and a complete change to an electrostatic application with redesign, safety interlocks, isolation stands, etc., may run more than $250,000. Worker safety is also a concern from electrostatic shocks and arcs in the presence of solvent fumes. EPA estimated transfer efficiency: >90%.

Process Control and Operating Practices

Since the basic chemical principles of metal finishing do not change, a process flow diagram of a 1940 operation would appear markedly similar to that of a 1998 facility. Technological advancements have largely centered on process chemistries and supplemental "output optimization" technologies to recover materials and treat wastes. Most of the major process improvement gains are in process control and operating practices, rather than "hard" technology, as these are likely to have a more direct and positive impact on quality and productivity.

Process control and optimization is "self-innovation" and a critical issue for metal finishers. Careful understanding and control of critical process parameters (temperature, flow rates, contaminant control, pH, density, etc.), optimization of rinsing practices, and process modifications (e.g., extended drain times and good parts orientation) are fundamentals in reducing wastes and minimizing the environmental effects from metal finishing operations.

Reduce Dragout. Another concern in metal finishing shops is the apparent conflict between improvement in cycle length and changes in operating practice required to minimize dragout. Process and operating modifications, such as extended drain times, may conflict with throughput objectives. Often missing from this analysis, however, are the cost considerations of losing process solution and its domino effect all the way to the treatment system. A more thorough analysis may point out that the benefits gained in cycle time reduction are lost due to the costs of wasteful manufacturing practices.

A second potential conflict between pollution prevention and manufacturing performance through dragout reduction is the potential contamination effects of the plating bath and their effect on product quality. Many metal finishers use dragout as a de facto means of purging impurities from process baths. The importance of process understanding and control is again evident. As a general rule of thumb: aggressive efforts to reduce dragout are a good thing if contaminant sources and their affect on baths is well understood.

Improve Process Controls. Of the parameters requiring control for platers, process solution contamination has some of the most severe effects. Increasing the frequency of bath dumps is one answer; other commonly applied corrective measures (such as increasing the concentration of chemicals to maintain efficiency) exacerbate dragout problems and increase electrical consumption. Solution maintenance technologies help preserve or restore the operating integrity of process baths and extend their useful lives. They are also used to improve operating efficiencies and effectiveness of solutions with subsequent benefits on production rates and product quality.

Preventive strategies to maintain bath life abound, but the primary question of "why" and "when" a bath becomes unusable remains a mystery in many operations. The two key factors are the proprietary nature of process chemistries and the lack of research on sources and effects of contaminants. Precise knowledge of the sources, chemical conditions, and circumstances leading to bath deterioration would greatly improve process control related to bath maintenance.

The general potential for contaminant source reduction through process optimization is rated as follows for several common plating processes:

Nickel	High
Noncyanide zinc	Low
Copper cyanide	Medium
Electroless nickel	High
Hexavalent chrome	High
Tin acid	Low
Cleaning baths	High

Once contamination has occurred, filtration removes suspended solids from solutions and carbon treatment removes organic contaminants. Both are very common and widely used in all types of metal finishing operations. There is often significant latitude in both these systems to improve regeneration efforts by 1) targeting filtration and treatment efforts to specific contaminants and 2) using the systems more efficiently by better understanding the specific cause-and-effect relationships between contaminant growth and regeneration needs. Employing both these strategies allows regeneration efforts to take place only when they are really needed.

Optimize Coating Application Practices. Proper equipment setup and adjustment is an essential aspect of reducing paint waste and improving coating application. The viscosity of the coating, the air and fluid pressures, the shape and size of the spray pattern, and the positioning and racking of work all influence transfer efficiencies and paint use. Careful attention to these process factors improves painting performance.

- Guns should be perpendicular to the surface whenever possible to reduce the chance of uneven paint coverage and paint bounce-back. Both tilting the gun (up or down) or arcing the gun (holding gun at an angle to the workpiece) is likely to result in these problems.
- The distance between the gun and work should be 6–12 inches. Too little distance results in runs and sags and inefficient application. Too great a distance results in overspray problems and uneven coverage.
- Timing the triggering of the gun is key to reducing overspray, conserving paint, and preventing excess material buildup. The gun movement should be started before triggering, and the trigger should be released before the stroke ends. Painters should strive for a 50% overlap on the return stroke for optimal efficiency.

Operator training has a significant influence on paint consumption rates and paint waste problems as well. Indirectly, operator training also affects the volume of solvents used for cleaning.

Improve Rinsing Efficiency. Countercurrent rinsing is a common arrangement for flow rinsing of parts. In this setup, the rinse tanks are arranged so that the part travels to progressively cleaner rinse tanks,"upstream" in the sense that the water input for the overall rinse is piped into the final "cleanest" rinse tank. Each tank in the series provides the water input for the tank that precedes it. The logic of countercurrent rinsing and the actual number of rinse tanks used are driven by both quality and economics. A general rule of thumb is that for each rinse tank added, the amount of water needed (to achieve the same quality rinse) can drop by a factor of ten. For example, if 100 gallons per hour is needed to rinse a part using one tank, only 10 gallons per hour will be needed to achieve an equivalent rinse through the installation of a second tank with counterflow rinsing. A third rinse tank would reduce water input to 1 gallons per hour. The concentration following the dead rinse typically drives the number of tanks; for some barrel plating operations where dragout is extremely high, six or more counterflow rinse tanks are used. There are limits for countercurrent rinsing since the line pressures involved in industrial processes are such that counterflow rinses cannot be controlled at input rates much under 0.5 gallons per hour. (See also the water flow-to-tank ratio description for calculating rinsing efficiency, p. 56.)

A qualifier to process improvement work in this area is worth mentioning. The concept of "closed-loop" or zero-discharge metal finishing systems has recieved much attention. Residuals are inevitable in metal finishing, and if they are not found in rinse waters, they will occur in bath dumps or in the residuals of various recovery and regeneration technologies. Water recovered and reused from the treatment system must be passed through reverse osmosis, sand filters, or carbon treatment before it can be used again. Pursuit of zero-discharge processing should be based on a determination that the regulatory and cost-benefits of near zero water discharge and water use reduction outweigh increased costs in hazardous waste disposal and shipping of spent process solutions.

Chemical Recovery

Recovery technologies are used to capture and separate metals and chemicals from rinse waters, and concentrate them. If recycling these materials back to the process tanks is technically feasible, regeneration technologies must often be used in tandem to remove contaminants and otherwise restore the solution. As a result, the useful lives of the process baths are extended, sometimes indefinitely. Recovery technologies have a direct environmental benefit in that they serve a pretreatment function for the facility wastewater treatment system—reducing the metal and chemical loadings of process rinse waters prior to their final treatment and discharge.

Recovery equipment is a well-established set of technologies. Supplier innovations focus on improving the recovery efficiency, effectiveness, durability, and operating "friendliness" of these systems. Industry surveys note that their use within finishing operations is frequently plagued by technical, design, maintenance, and operating problems. The 1994 NCMS study noted that 30–40% of recovery efforts have not been successful. However, their secondary use as "pretreatment" for the facility wastewater treatment system makes this set of technologies an important element for many plating operations.

Recovery Dragout. There are three principal categories of dragout recovery: direct dragout, atmospheric evaporation, and electrowinning.

Direct dragout is not a technology per se but a practice used to return and reuse diluted process solution. After the process tank, parts enter a "dead rinse" or "still rinse" to remove process chemistry, which is then returned to the process tank. This simple strategy, however, has three limiting characteristics. First, dragout recovery returns contaminants, as well as process solution, and the contaminants can build up to problem levels. Second, it can also build up metal values to inappropriate levels. Third, direct recovery requires solution temperatures in excess of 130°F to create the necessary evaporation or "headroom" in the process tank for solution return.

Atmospheric evaporation is an add-on technology to overcome the "headroom" issue and allow dragout recovery. As before, the dead rinse tank solution is returned to the process solution tank to recover chemicals. In addition, the process solution is first pumped from the process tank into the evaporation unit where the heat present in process solution is used to "humidify" the air blown through the evaporator. This concentrates the solution and makes it suitable for return to the process tank. Most atmospheric evaporators are used to recover nickel from the dragout of nickel plating baths and hexavalent chrome from chrome plating bath dragout. They are also used on copper cyanide, acid and alkaline zinc, and trivalent chrome baths. They are relatively simple technologies, use relatively little electrical energy, and are perhaps the least expensive of the recovery technologies to purchase and operate. Atmospheric evaporation units typically cost $5000–$15,000 fully installed. Annual operating costs average about half the capital cost.

Electrowinning is a widely used metal recovery technology. In this case, a charged electrolytic cell removes metal ions. This simple technology is occasionally constructed in-house and is commonly used on cyanide-based metal solutions. Chromium is the only commonly plated metal that is not recoverable by electrowinning. It is typically used on high concentration baths such as dead rinses immediately following the plating baths. The capital cost is a function of the design features and capacity. The purchase price can range from $1000 to $100,000. Operating costs are relatively low since the technology is not labor-intensive or expensive to run.

Ideally, these dragout recovery technologies are employed for in-process recycling to return materials back to the original process bath, thus reducing waste and saving input material costs. However, several issues must be considered in evaluating the desirability of implementing any of these technologies from the standpoint of achieving the joint goals of improved environmental performance and productivity.

- Recovery and return techniques can result in potential quality problems. All three identified technologies create two problems that limit their application and acceptance by metal finishers. First, impurities that are normally purged by dragout can accumulate and sometimes concentrate, resulting in product quality problems. Second, baths using soluble anodes have a tendency to build up in concentration if dragout is returned. This "bath growth" can cause other process imbalances, particularly with nickel.
- Overcoming these quality concerns often requires additional capital investment in

solution maintenance technologies. These technologies purify the recovered materials before reintroduction to process baths. This adds to the capital investment requirement and operating costs and may be economically feasible for high-value baths and high-volume operations only.

- Full technology implementation still does not guarantee success. The NCMS metal finishers survey noted that 30–40% of these recovery efforts have not been successful. Even with subsequent investments in regeneration technologies, their application is frequently plagued by technical, design, maintenance, and quality problems. Combined with their general complexity, the utility and performance of these technologies in materials recovery can be overrated.
- Optimum performance of recovery systems is dependent on careful process control. The best application and utilization of these technologies often depends on other practices. The potential recovery and quality problems highlighted above can be minimized by thorough maintenance of key process parameters and an understanding of contaminant issues.

Energy Use

Benchmarking data from the Industrial Technology Institute show that 73% of metal finishers have taken simple measures to save energy, such as switching to high-efficiency lighting and/or capturing air compressor leaks, and 65% have likewise changed production equipment or practices. Despite these good adoption rates, just 23% track energy use by machine or activity; 16% have facilitywide demand control systems; and only 26% have heat recovery systems, even though these are well-known energy savers. In many cases, the lack of follow-through on promising opportunities appears associated with the need for preliminary site analysis work. Changing light bulbs requires virtually no analysis; justifying high-efficiency motors necessitates some load monitoring. Utility staff can provide important assistance in evaluating opportunities and support in their implementation.

Reduce Heat Loss. Open, heated process tanks represent an area of high energy loss. “Ball blankets” are a simple but underutilized solution, employing a layer of plastic balls to cover the process tank surface, thereby minimizing evaporative heat loss. Applying a ball blanket to an 8 x 24 foot tank maintained at 190°F would reduce tank energy loss by 75%. The annual energy cost savings from this application, assuming burner tip energy costs of $7.07/MMBtu, would amount to $16,000. With the average cost of ball blankets being $10/square foot, covering the 192-square foot surface area of the tank would cost $1920, giving a simple payback of about two months for this conservation technique.

Reduce Peak Loads. The potential improvements to energy use in metal finishing facilities are highly interconnected. The first step is to meter loads, both to understand efficiencies and to locate demand peaks. In some cases, demand peaks with shop startup in the morning, because all motors and rectifiers are brought into operation nearly simultaneously. In other cases, peak demand occurs later in the first shift, when all lines are “loaded” and fully operational. In still other cases, demand does not show a “needle peak” but is higher than necessary because all drive motors are run continuously rather than only when loaded. Pinpointing the timing, size, and causes of demand enable informed decision making about energy control options. Installation of an energy management control system is a sure solution to optimizing energy use over the long run.

Improve Equipment Efficiency. High-efficiency motors and variable-speed drives are typically only feasible to install when existing equipment requires replacement. However, the sheer number of small- to medium-size motors in metal finishing operations makes replacement a fairly frequent activity. Matching motor size to task also has implications for energy efficiency and is commonly overlooked or misunderstood in the purchasing procedure. Here, again, load monitoring would be of great benefit in the decision-making process.

Switching to aluminum cathodes for anodizing solutions can lower total energy bills by reducing the load on the process refrigeration system, since aluminum cathodes operate at relatively lower temperature. In addition to the savings due to reduced refrigeration costs, properly installed aluminum cathodes also allow a 1–2 V reduction in cell voltage during the anodizing cycle, as compared to standard lead cathode systems. For example, lead anode anodizing consumes 10–20 kW more electrical energy than an aluminum cathode system when a 10,000 ampere rectifier is used to full capacity.

TYPES OF ASSISTANCE NEEDED

Table 15 links process improvement opportunities with specific types of assistance an energy supplier might provide to support implementation of the improvement. Simple definitions of these assistance types are provided here.

Engineering Support

Metal finishers often lack on-site staff with the engineering expertise required to perform detailed process analysis, options analysis, or calculations related to equipment sizing, installation, or performance. Instead, they rely on either consultants, who are expensive, or suppliers, who do not consider any analysis beyond that required to sell their product/system. Outside, neutral-party engineering assistance focused on these issues is seen as valuable.

Options Research

Once a set of process improvement opportunities have been identified, many metal finishers lack the research skills and engineering expertise to sort the set for feasibility and compare costs and benefits. Assistance in this area would involve accessing research databases and experts and then combining that information with site-specific data to help a company make good choices. Once again, the perception of a utility's neutrality is a trust-building value; the utility would have no stake in the metal finisher's final decision other than wanting to improve the overall competitiveness of the particular business.

Pilot Studies

Once improvement opportunities have been identified, another implementation difficulty for metal finishers is the period of "scale-up" or "shakedown," when new equipment and/or chemicals are used—first at experimental scale and then in the production environment. Assistance in this area would include such activities as experimental design, scaled experiments, and process monitoring, all designed to provide a company some assurance that the newly instituted process improvement will not fail catastrophically. Demonstration facilities and tours of sites where a proposed process has been implemented also help raise the comfort level.

Activity-Based Costing

Before an opportunity can be analyzed, it must be discovered. In many companies, the key to discovering opportunities is understanding costs more completely, especially the allocation of those costs to specific activities. This allocation is the gist of activity-based costing (ABC). In the metal finishing industry, however, in-depth knowledge of costs is fairly rare, and cost allocation nearly nonexistent. An outside assistance provider—an energy supplier—with the skills to break down aggregated cost categories such as “materials” and “energy” into detailed cost profiles provides the necessary first step to scoping potential projects.

Quality Control/Quality Assurance Systems

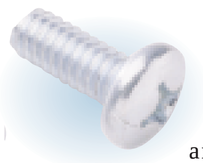
Process improvement (improving process quality) and product quality are inextricably linked, yet many metal finishers are far better at detecting and correcting rejected parts than they are at the recordkeeping, data display, and root-cause analysis needed to move from treating symptoms to solving problems. Outside assistance providers with these skills can help metal finishers build better management systems, which will improve their competitiveness, and simultaneously set the stage for the identification and implementation of process improvements.

Energy-Use Tracking

Energy consumption analysis and load monitoring provide cornerstone data for improvements related to energy-using equipment and energy cost control. Utilities have obvious expertise in this area. Energy audits are seen as well within an energy supplier’s purview and are welcome assistance.

four

Examples of Targeting and Assistance



This chapter presents “case study” examples of the three-level targeting analysis for three companies. All three companies perform electroplating; two perform zinc plating and one provides both zinc and nickel plating services. Completed analysis matrices are provided for each company. One company “passes” to Level 3, so process improvement opportunities are also identified and described for this company. The examples assume a telephone interview was conducted with each company to ask the questions posed for each level of the analysis. The analysis matrices were completed following this interview. Experience shows that companies responding to the 22 questions in the analysis matrices commonly provide more information than requested, as is shown in examples.

CASE STUDY: Company A

Company A was founded in 1930 and employs 10 people in production, support, and management. Company A’s production focuses on the electroplating of fasteners, housings, and related products for a variety of customers. The majority of the electroplating is zinc plating followed by a chromate conversion coating. Other plating finishes include silver, tin, and chrome. The physical plant dates from the founding of the firm. Company A’s competitive advantage is its ability to provide very quick turnaround, usually only one or two days, for a variety of finishes. The firm was purchased by the current owner two years ago.

Company A Findings

- Company A’s competition is larger electroplating job shops. These shops tend to have more flexibility on price and better ability to process large orders. All competition is local; Company A believes no orders have been lost to metal finishing facilities in Mexico.
- Mechanical finishing is not an option for any of the sheet stock or tubular parts processed. Although fasteners could be finished mechanically, it has not been requested.
- Some orders for flat stock finishing have been lost to powder coating, but this process is not seen as a competitive threat because of the company’s small lot sizes, which generally make powder coating too expensive.
- Company A’s customers reject fewer than 1% of the lots they receive. This level of product acceptance is assured by providing plating thicknesses that are well above the minimum required. Internal rejects, when they occur, generally are detected by operators as they conduct their pro-

duction operations on the parts and can be reworked in-process, especially with zinc plating.

- Cadmium has been a problem in terms of meeting wastewater discharge limits.
- The facility will need a permit under the CAAA for chromium releases.
- Costs to operate the pretreatment system are estimated to be $50,000 per year, and the facility is operating under an enforcement decree from the local POTW.
- Zinc plating is 85–90% of total production volume, and is usually applied to a "commercial" thickness of 0.0002 inch.
- Cyanide is used in process solutions for plating cadmium, silver, and copper.
- Company A has over 100 customers. Sales have been flat from 1996 to present and currently total $750,000 annually.
- Plating operators are experienced, having been with the company a minimum of eight years.
- Water use has been reduced from 10,000 gallons/day to 6000 gallons/day, but extra charges have held the annual costs steady.
- Company A has the following material inputs to its production process (annual):

Material Inputs	Quantity/yr	Cost/yr
Water	6000 gal/day	$6000
Muriatic acid	29,000 lb	$3500
Caustic soda	23,000 lb	$2400
Cleaner	8,800 lb	$5800
Zinc starter	2,200 gal	$5400
Calcium chloride	22,000 lb	$3400
Zinc anodes	2,500 lb	$5000
Cyanide	500 lb	$1000
Nickel	500 lb	$1800
Cadmium	750 lb	$750
Solvent	150 gal	$600
Ferric chloride	2,700 lb	$1800
Sodium hydroxide	220 gal	$2400
Sodium bisulfite	2,700 lb	$1000
Sodium hypochlorite	500 gal	$500
Polymer	10 gal	$200

- Company A has the following outputs from its production process (annual):

—50,500 pounds of sludge, which costs $10,300/year to dispose

—1.548 million gallons of wastewater, which costs $2817/year to dispose

- Company A has the following energy inputs (entire facility):

—$26,400/year for electricity

—$20,000/year for natural gas

Company A Analysis

Long-term viability: Company A is not currently exposed to any direct competition from Mexico, but is very concentrated in a low-value-added coating (zinc) that is one of the most common to be supplied from Mexico. The company is under no threat from alternative methods. It is under environmental pressure, however, with not only an open enforcement action, but the need to analyze and comply with a new air permit requirement. On the management side, the owner is inexperienced and deeply in debt from the purchase of the company.

Level 1 Score = 45, plus additional concerns about debt, experience, and regulatory enforcement action.
Recommendation: Does not pass to Level 2. Refer to state technical assistance program if interest is shown.

CASE STUDY: Company B

Company B employs about 1800 people in in the manufacture of floor care equipment for domestic use (vacuum cleaners, etc.); metal finishing is conducted as a captive operation. While the physical facility dates back to Company B's early days as a large manufacturer, large capital investments have modernized both the facility and production equipment. Company B's competitive advantage is its well-known name, a recognition built on a series of patented innovations that have continued to set the pace in this market. Annual sales are roughly $80 million. Of that, about $1 million is estimated from "value-added" metal finishing.

Company B Findings

- Company B's competitive advantage is its skill in product design, which allows it to "innovate ahead" of other firms and capture the largest share of the market and be the leader in the floor care industry.
- Company B's emphasis in production is to use outside suppliers as little as possible, believing that this gives a high level of control and certainty that leads to quicker time to market and higher levels of product quality.
- Competition from metal finishers in Mexico is seen as a moot point for the captive metal finishing operations.
- Product quality is of the utmost importance, and is assured by extensive testing of both components and samples of every sweeper assembled. Rejects, when they occur, generally are detected at the component level.
- Neither mechanical finishing nor powder coating are believed appropriate alternatives to the plating currently performed at this site (these processes are used for specialty applications at other company sites).
- Even with support operations such as cleaning, plating, and chromating, Company B remains very much like any other assembly operation in terms of materials use and waste. This means that waste volumes are quite small in a relative sense. For example, costs for cleaners average less than 0.01% of total purchases of process chemistry for electroplating.
- Current costs of waste management are not seen as significant when compared to other costs such as labor; however, they

TABLE 18. Level 1 Analysis: Company A

Discriminants	Questions	Possible Scores		Company Score
Exposure to international competition	Have you lost sales to metal finishers in Mexico?	Yes = No =	5 0	5
Competition from alternative methods	Could mechanical finishing be used to coat any products you currently plate?	Yes = No =	10 0	0
	Could powder coating be used to coat any products you currently paint?	Yes = No =	10 0	0
Relative proportion of high-/low-value-added	Is the majority of your finishing highly specialized, with strict quality control requirements?	Yes = No =	10 0	10
Environmental pressure	Do you have or need an air permit?	Yes = No =	10 0	10
	Have your costs to sewer water increased the last two years, or are those costs about to increase?	Yes = No =	10 0	10
	What are your environmental costs as a % of sales? (treatment, disposal, labor, administration)	< 0.1% = 0.1–0.3% = 0.3–0.7% = 0.7–1.7% = 1.7–3.0% = > 3.0% =	0 1 4 6 8 10	10
		Total Score:		45
	Rank for Level One	Long-term survival difficult		≥ 45
		Pass to Level Two		< 45

are reviewed and tracked on a monthly basis by the Waste Minimization Committee. Waste managment costs average about $4000 per year for metal finishing activities (about 0.4% of metal finishing sales). All solvent use has been eliminated.

- The facility attributes no costs to sewer water, since all water is treated on-site and discharged to an on-site lagoon. This lagoon will be closed by the year 2003.
- The facility is permitted under the CAAA for styrene releases.
- Cleaning and etching solutions are dumped on a calendar basis because maintenance is easier to schedule when solution dumps are predictable. An alternative method, dumping when contaminants reach predetermined levels, is not thought to be financially justified.
- Year-to-date costs (6.5 months of operation) for plating chemicals were $38,450. Cleaners were responsible for 60+% of these costs. Costs for the 250,000 gallons of water used annually for rinses are negligible because the source is an on-site well.
- Energy costs for metal finishing activities are less than $21,000 per year.
- The reject rate in the metal finishing area was very low, less than 0.5% of total parts processed per year.
- The facility's conversion efficiency for electroplating (amount of metal used that becomes plating on parts) is estimated at 82%.
- The waste minimization effort has reached a plateau in terms of finding new targets. It is generally believed that more improvements are possible, but also that any future improvements will be more difficult to justify financially.

TABLE 19. Level 1 Analysis: Company B

Discriminants	Questions	Possible Scores	Company Score
Exposure to international competition	Have you lost sales to metal finishers in Mexico?	Yes = 5 No = 0	0
Competition from alternative methods	Could mechanical finishing be used to coat any products you currently plate?	Yes = 10 No = 0	0
	Could powder coating be used to coat any products you currently paint?	Yes = 10 No = 0	0
Relative proportion of high-/low-value-added	Is the majority of your finishing highly specialized, with strict quality control requirements?	Yes = 10 No = 0	0
Environmental pressure	Do you have or need an air permit?	Yes = 10 No = 0	10
	Have your costs to sewer water increased the last two years, or are those costs about to increase?	Yes = 10 No = 0	0
	What are your environmental costs as a % of sales? (treatment, disposal, labor, administration)	< 0.1% = 0 0.1–0.3% = 1 0.3–0.7% = 4 0.7–1.7% = 6 1.7–3.0% = 8 > 3.0% = 10	4
		Total Score:	14
	Rank for Level One	Long-term survival difficult	≥ 45
		Pass to Level Two	< 45

Company B Analysis

The long-term viability of the firm, and specifically of its zinc plating operation, would seem to be excellent. Company B is not exposed to any competition from Mexico, and all zinc plating for this multinational is now concentrated in this one location. The firm is under no threat from alternative methods. It is under no environmental pressure, with the small exception of ongoing closure of the on-site lagoon.

Level 1 Score = 14
Recommendation: Pass to Level 2

TABLE 20. Level 2 Analyis: Company B

Process Area	Questions	Timeliness Scores		Company Score
Metal cleaning/ surface preparation	How many gallons of solvent does your facility use per $100,000 of finishing sales?	< 10 gal = 10–100 gal = 100–600 gal = 600–2700 gal = 2700–5400 gal = > 5400 gal =	0 1 4 6 8 10	0
	How much do you spend on cleaning chemistry as a % of all process chemistry purchased?	< 0.5% = 0.5–1.5% = 1.5–2.5% = 2.5–3.5% = 3.5–4.5% = > 4.5% =	0 1 4 6 8 10	0
Finishing processes: plating/coating (choose one)	How much of the metal purchased for plating solutions becomes plating on parts? (OR)	> 95% = 85–95% = 80–85% = 70–80% = 60–70% = < 70% =	10 8 6 7 8 10	6
	How much of the paint (as solids) purchased becomes coating on parts?	> 90% = 80–90% = 40–80% = 30–40% = 20–30% = < 20% =	10 8 6 7 8 10	1
Waste handling processes	How many gallons of rinse water are used per $100,000 of finishing sales?	< 36,000 gal = 36,000–97,000 gal = 97,000–213,000 gal = 213,000–427,000 gal = 427,000–894,000 gal = > 894,000 gal =	1 2 4 6 8 10	1
Energy use	What are your energy costs as a % of sales?	< 2.1% = 2.1–3.2% = 3.2–5.4% = 5.4–6.7% = 6.7–9.4% = > 9.4% =	0 2 4 6 8 10	0
		Total Score:		**8**
	Rank for Level Two	Processes at or near best-practice level		≤ 18
		Pass to Level Three		> 18

The categorization matrix suggests that firms that pass Level 1 should next be analyzed for whether process improvement is timely. Company B not only has best-in-practice figures for all its material inputs, it has a Waste Minimization Committee of long standing that is continuously improving the few remaining processes that need such attention. In the "big picture" a project there would not be successful.

Level 2 Score = 8
Recommendation: No assistance. As a captive operation, internal resources are plentiful and experienced.

CASE STUDY: Company C

Company C was founded in a new facility in 1969 and employs about 20 people in production and 10 more in administration and management. Currently, large capital investments are being made to expand operations in a nearby building. Company C's production focuses on the electroplating and conversion coating of connectors, housings for electronics equipment, wire goods, and wire shelving, among other products. Nickel, nickel and chrome, electroless nickel, and zinc plating are provided, with somewhat smaller operations devoted to anodizing, passivating, silver plating, tin plating, polishing, and assembly. Company C's competitive advantage is to do quick turnaround plating to very high-quality standards. Metal finishers in Mexico are not seen as a competitive threat because of shipping times and quality issues. Annual sales are about $3 million.

Company C Findings

- Company C's competitive advantage is its skill in production management and

TABLE 21. Level 1 Analysis: Company C

Discriminants	Questions	Possible Scores	Company Score
Exposure to international competition	Have you lost sales to metal finishers in Mexico?	Yes = 5 No = 0	0
Competition from alternative methods	Could mechanical finishing be used to coat any products you currently plate?	Yes = 10 No = 0	0
	Could powder coating be used to coat any products you currently paint?	Yes = 10 No = 0	0
Relative proportion of high-/low-value-added	Is the majority of your finishing highly specialized, with strict quality control requirements?	Yes = 10 No = 0	0
Environmental pressure	Do you have or need an air permit?	Yes = 10 No = 0	0
	Have your costs to sewer water increased the last two years, or are those costs about to increase?	Yes = 10 No = 0	10
	What are your environmental costs as a % of sales? (treatment, disposal, labor, administration)	< 0.1% = 0 0.1–0.3% = 1 0.3–0.7% = 4 0.7–1.7% = 6 1.7–3.0% = 8 > 3.0% = 10	10
		Total Score:	20
	Rank for Level One	Long-term survival difficult	≥ 45
		Pass to Level Two	< 45

process management, which allow it to achieve quick turnaround of high-quality specification plating for its target markets.

- Product quality is very important and is assured by testing of both process solutions and parts. Rejects, when they occur, generally are detected by operators during loading and unloading of parts.
- Neither mechanical finishing nor powder coating are seen as viable alternatives for the parts finished.
- Waste volumes are quite small in a relative sense compared to other electroplaters with a similar product mix and age of facility of equipment, but the costs to sewer wastewater have increased dramati-

TABLE 22. Level 2 Analysis: Company C

Process Area	Questions	Timeliness Scores		Company Score
Metal cleaning/ surface preparation	How many gallons of solvent does your facility use per $100,000 of finishing sales?	< 10 gal = 10–100 gal = 100–600 gal = 600–2700 gal = 2700–5400 gal = > 5400 gal =	0 1 4 6 8 10	0
	How much do you spend on cleaning chemistry as a % of all process chemistry purchased?	< 0.5% = 0.5–1.5% = 1.5–2.5% = 2.5–3.5% = 3.5–4.5% = > 4.5% =	0 1 4 6 8 10	10
Finishing processes: plating/coating (choose one)	How much of the metal purchased for plating solutions becomes plating on parts? (OR)	> 95% = 85–95% = 80–85% = 70–80% = 60–70% = < 70% =	10 8 6 7 8 10	7
	How much of the paint (as solids) purchased becomes coating on parts?	> 90% = 80–90% = 40–80% = 30–40% = 20–30% = < 20% =	10 8 6 7 8 10	0
Waste handling processes	How many gallons of rinse water are used per $100,000 of finishing sales?	< 36,000 gal = 36,000–97,000 gal = 97,000–213,000 gal = 213,000–427,000 gal = 427,000–894,000 gal = > 894,000 gal =	1 2 4 6 8 10	2
Energy use	What are your energy costs as a % of sales?	< 2.1% = 2.1–3.2% = 3.2–5.4% = 5.4–6.7% = 6.7–9.4% = > 9.4% =	0 2 4 6 8 10	10
		Total Score:		**29**
	Rank for Level Two	Processes at or near best-practice level		≤ 18
		Pass to Level Three		> 18

cally in recent years and are predicted to rise higher. The facility does not require an air permit.

- Solvents have been eliminated from the facility, for which the company won a Governor's Award for Pollution Prevention.
- Cleaning and etching solutions are dumped on a calendar basis because maintenance is easier to schedule when solution dumps are predictable. Dumping costs are about $10,000 annually. An alternative method, dumping when contaminants reach predetermined levels, is not thought to be financially justified.
- Concentrations of the constituents in process solution is seen to be a critical process concern.
- The annual cost for plating process chemistry and anodes for zinc plating and nickel/chrome plating on all lines is $183,287.
- The annual cost to purchase water, treat wastewater, and dispose of pretreatment sludge (i.e., the facility's environmental costs) is $243,852 (8.1% of sales).
- The overall reject rate in the facility is fairly low (about 2%), but increasing attention is being given to reducing product defects. Estimated costs to rework internal rejects on all lines is estimated at $150,000 in 1997, $220,000 in 1996.
- The combined line and the zinc line processed approximately 660,268 square feet of parts needing nickel plating, and 2,076,178 square feet of parts needing zinc plating, in 1997. Average thickness of the nickel plate is 0.00055 inch; thickness of the zinc plate is 0.00065 inch. The facility's conversion efficiency (metal inputs to metal plating) is about 72%.
- Most production (85% of total) is processed with automated equipment; about 50% of the equipment is 2–10 years old.
- Training and retention of qualified technical and operations staff is a growing concern, and is thought to be affecting product quality.
- Annual water use is about 1.5 million gallons. Water use reduction is a critical issue, and efforts are being made in the new facility to re-use substantial quantities of process wastewater.
- Dragout from process solutions was mentioned by facility staff as a possible target for process improvement.
- The average plating thickness on parts may be more than is strictly necessary, leading to a possible waste of raw materials.
- Energy use for the entire facility is $300,000 per year.

Company C Analysis

The long-term viability of the firm, and specifically of its zinc plating operation, seems to be excellent. Company C is not exposed to any competition from Mexico, and in fact recently some zinc plating has been "won back" from a metal finisher in Mexico because of quality concerns. The company is under some threat from alternative methods, specifically mechanical finishing of fasteners, but this is only 10% of the business. It is under no environmental pressure, especially having recently won the Governor's Award for Pollution Prevention.

Level 1 Score = 20
Recommendation: Pass to Level 2

Company C has a low-end technology profile for many of its material inputs, suggesting that profitability could be improved dramatically. Energy use in particular seems worthy of attention.

Level 2 Score = 29
Recommendation: Pass to Level 3

Firms that pass both Level 1 and Level 2 have both long-term viability and process improvement opportunities. The final analysis, Level 3, looks at a firm's ability to analyze and implement process improvements. Company C is an excellent candidate for process improvement success for the following reasons:

- High value-added per employee (>$125,000)
- Open specifications for 85% of its finishing
- High incidence of long production runs
- Considerable amount of new equipment, and in the process of expanding
- Considerable prior activity in waste reduction
- 80% automated equipment

Level 3 Score = 69
Recommendation: Proceed with assessment to scope possible projects.

TABLE 23. Level 3 Analysis: Company C

Discriminants	Questions	Possible Scores		Company Score
Product-related variables	What is your value-added per shop employee? (finishing sales ÷ # shop employees)	> $125,000 = $88,000–$125,000 = $67,000–$88,000 = $49,000–$67,000 = < $49,000 =	8 6 2 0 10	10
	What are the most common specifications for the finishing you perform?	Performance or open specs. = Process specs. =	2 10	10
	What percentage of your production is parts that require more than one shift to process and are processed at least four times per year?	100% = 80–100% = 50–80% = 30–50% = < 30% =	9 8 6 0 10	9
Process-related variables	What percentage of your production is processed using automated equipment?	100% = 70–100% = 30–70% = <30% =	10 9 6 0	9
	How old is your physical plant?	< 10 yr = 10–20 yr = > 20 yr =	10 5 0	0
	What percentage of your production equipment has an age of 2–10 yr?	100% = 75–100% = 25–75% = < 25% =	0 5 10 0	10
Management variables	What percentage of total production is scrapped or reworked before shipment? (internal rejects)	< 0.35% = 0.35–1.0% = 1–3% = 3–5% = > 5% =	10 8 6 4 0	6
	Is your facility a captive operation or a job shop?	Captive = Job shop =	10 0	5
	Have you implemented waste reduction or energy saving practices in the last five years?	Yes = No =	10 0	10
		Total Score:		**69**
	Rank for Level Three	Implementation Success Not Likely =		≤ 55
		Implementation Success More Likely =		> 55

Assistance to Company C

The next step in evaluating options to assist this company with process improvements is to review its Level 2 "timeliness scores" against the opportunities presented in table 15 (see p. 53). The timeliness scores suggest four areas for further investigation: use of cleaners, reduction in dragout, rinsing efficiency, and process heat loss. Activity-based costing and standard engineering calculations can be employed to determine current business costs and potential cost-benefits from process improvement.

OPTION 1: Recover and return dragout of nickel plating solution to process tanks; reduce dragout by increased drain time

Understanding the potential of these opportunities requires knowing the current use (cost) of nickel plating solution and then contrasting this with the costs associated with different types of losses.

Only monitoring and direct measurements can establish the actual cost of dragout. These calculations, however, use conservative assumptions and do not even account for the effects of dragout (e.g., contamination of subsequent process solutions and costs related to such contamination and wastewater treatment). It is likely that the costs of dragout are somewhat higher than estimated here, even if only raw material costs are considered. A very simple change, such as extending part drain time a few seconds, could reduce dragout by up to 25%, which would have a value of over $75,000 anually.

POTENTIAL SAVINGS from 25% dragout reduction: $75,000+/yr

Cost Assessment:
OPTION 1

Materials costs associated with nickel plating	
(24,000 lb nickel chips/yr)($3.25/lb) =	$78,000/yr
Nickel plating process chemistry =	$25,662/yr
A portion of pretreatment costs are also allocated to the cost of dragout, since reducing dragout should allow a commensurate reduction in water use and sludge volume.	
($243,852 total cost of pretreatment)(40% of pretreatment need due to nickel) =	$97,540/yr
Total cost of dragout from nickel plating =	$201,202/yr
The cost of lost process chemistry for nickel plating is estimated next, since this is the only solution of the two with sufficient evaporation to theoretically provide head room for dragout return.	
(2 gal/hr dragout)(6300 hr/yr)($8.50/gal) =	$107,100/yr
Assumptions: 1) 2 gal/hr dragout 2) 6300 hr/yr operation, and value of nickel plating solution = $8.50/gal	
Total cost of nickel dragout =	**$308,302/yr**

OPTION 2: Redesign rinse tanks to increase sparging and temper water temperature and thereby reduce and/or improve spray rinses

Rinsing processes do not appear well optimized. The spray nozzles themselves seem the most likely focus of an initial investigation, both because they are visually obvious and because a large body of knowledge exists to support such a process change. Sparging to increase agitation and improve the dilutive effects of the rinse water, and tempering the water to 70˚F are two well-known approaches to reducing water use, sometimes as much as 2 gallons per minute per rinse. Cost data and standards for rinsing efficiency are needed to assess the potential value of these changes.

The cost of inefficient rinsing is the difference between the actual cost and whatever is found to be optimal, given the specifics of the line and the product processed. Even an improvement as small as a 10% reduction in water use has the potential to save almost $25,000 per year for Company C. Improved rinsing has the potential to save not just water but also extend the life of process solutions and reduce rejects. Before changes can actually be made, however, rinsing standards will be needed.

POTENTIAL SAVINGS from 10% reduction in water use: $25,000/yr

OPTION 3: Reduce heat loss by installing floating "ball blankets" on heated solutions on the combined process line

Without direct measurements, delivering an accurate energy analysis regarding evaporative losses is very difficult. However, using standard engineering calculations and knowing the surface area of the tanks and the temperature of each tank, along with data on the effectiveness of ball blankets at preventing evaporative losses, allows development of a conservative estimate of savings potential.

POTENTIAL SAVINGS with ball blankets: $26,000+/yr

Total Potential Savings

These calculations give Company C a conservative, well-founded estimate of potential cost savings from three types of process improvements. Implementing simple changes to reduce dragout by extending drain time a few seconds; improving rinsing procedures to reduce water use 10%; and installing ball blankets on heated process tanks could save Company C more than $126,000 per year:

$75,000+/yr from dragout reduction
$25,000/yr from reduced water use
$26,000+/yr using ball blankets to cut evaporative heat losses

TOTAL POTENTIAL SAVINGS:
$126,000+/yr

Cost Assessment: **OPTION 2**

Tap water use	
31,108,210 gal/yr ($7.65/1000 gal) to buy, treat, and dispose =	$237,971/yr
Deionized water use	
$5800/yr to generate =	$5,800/yr
Total cost of rinsing =	**$243,771/yr**

Cost Assessment: **OPTION 3**

Calculation for combined lines	
($300,000)(15%)(50%)(30%) =	$6,750/yr
($300,000)(10%)(8)(50%)(30%) =	$36,000/yr
Cost of heat energy lost due to evaporation =	$42,750/yr
Use of ball blankets prevents 75% of heat losses =	$32,000+/yr
Estimated cost of ball blankets for all heated tanks =	$6,000
Assumptions: 1) $300,000 annual cost for electricity, all uses, 2) 50% of electricity used to heat process solutions, 3) 30% of heating energy lost due to evaporation, 4) main line uses 15% of total energy, and 5) each of eight other lines use 10% of total energy	
Potential savings with ball blankets	**$26,000/yr**

a
Technology Profiles

This section provides profiles of some of the technologies identified in chapter 2. Each profile explains the technology, its advantages/disadvantages, commercial status, costs, and materials inputs/outputs. The profiles have been designed as stand-alone descriptions so they can be utilized separately from this guide. Turn to appendix B for a list of equipment vendors that can provide further information as needed.

The technologies profiled in this appendix are

- Aqueous & Semi-Aqueous Cleaning
- Electric IR Drying & Curing
- Electrolysis
- Ion Exchange
- Membrane Filtration
- Metal Spray Coating
- Physical Vapor Deposition
- Powder Coating
- Ultrasonic Cleaning
- Ultraviolet Curing
- Vacuum Evaporation

Aqueous & Semi-Aqueous Cleaning

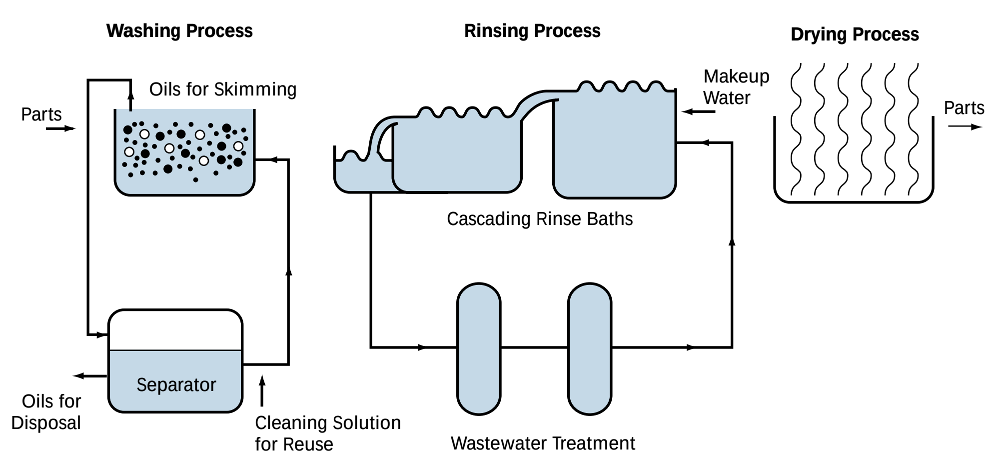
BASIC PRINCIPLE

The phaseout of many chlorofluorocarbons (CFCs) by the Clean Air Act Amendments of 1990 is forcing the metal finishing industry to look for CFC-free approaches to cleaning parts prior to plating or coating. Among three alternatives—nonhalogenated solvent-based systems and aqueous and semi-aqueous solutions—the latter two are preferred for environmental reasons and their ability to work well on most metals and metal alloys. They are also typically less expensive than solvents and easier to use in most applications.

Aqueous solutions are customized to meet specific cleaning application requirements and are typically classified according to pH. Alkaline cleaners (pH>9) are the most commonly used cleaners in this family. They contain three elements: alkaline salts or builders, organic and inorganic additives, and surfactants. Alkaline cleaners are most effective at cleaning insoluble particles and organic contaminants such as oils, grease, and lubricants. Acid cleaners (pH<7) contain inorganic acids, acid salts, and wetting agents or detergents; they can be used to remove dirt, oil, or oxides from metal surfaces.

Semi-aqueous cleaning uses hydrocarbons—terpenes, dibasic esters, glycol ethers, and n-methyl pyrrolidone—in combination with surfactants and water to remove heavy grease, tar, waxes, and hard-to-remove soils. Parts are dipped into a concentrated hydrocarbon/surfactant bath, and/or into an emulsified bath, then rinsed with water to remove residue. The water rinse can be eliminated if the process includes an emulsion wash or if the part can tolerate the residue of the cleaner.

Aqueous and Semi-Aqueous Cleaning



SYSTEM DESCRIPTION

There are four steps to aqueous and semi-aqueous cleaning: washing, rinsing, drying, and wastewater treatment and disposal. Although each step is important, rinsing and drying are not necessary in all cases, and wastewater treatment and disposal can be integrated into other steps through the use of recycled baths. Also, in a semi-aqueous system, use of a decanter to separate water and solvents allows subsequent reuse of both process materials.

Washing Process

In both aqueous and semi-aqueous systems, immersion is the most common washing process. In this process, heat or mechanical agitation is used to create currents that remove contaminants from the part surface. Metal finishers can enhance the cleaning process by adding rotary baskets, spray washing systems, and/or ultrasonic cleaning equipment. However, facilities using semi-aqueous solutions with spray systems or heat must exercise caution because some hydrocarbons are combustible at low temperatures and pressures.

Drying Process

Drying can be accomplished with high- or low-velocity drying, drying ovens, IR heating lamps, centrifugal drying, or vacuum oven drying. Compact turbine blowers with high-velocity forced air can remove as much as 90% of the water, reducing drying time and minimizing water spots and stains. Drying ovens, IR heating, or centrifugal drying can then be used as a secondary drying method to evaporate the remaining solution. For metal parts with complex geometries, vacuum oven drying can be an effective secondary drying method to ensure the complete removal of water.

Wastewater Treatment

The wastewater generated in both aqueous and semi-aqueous cleaning can contain detergents, surfactants, dissolved or suspended metals, and organic components such as oils and grease. Therefore, pretreatment may be necessary prior to discharge. Some innovative pretreatment options include membrane filtration, ion exchange, and vacuum evaporation.

KEY INPUTS

Process chemistry used in these systems can range from simple solutions of potassium hydroxide to very complex mixtures of caustic materials, organics to hold or release different types of soils, and organic solvents or co-solvents. Costs can range from as low as $0.10/lb to over $10.00/lb, depending on the exact application. Water, once an innocuous input, is now required to be purified or deionized in high-end systems, and has become a critical input. Energy inputs are also important because of the high temperatures of many solutions (and potential for high evaporative heat loss).

KEY OUTPUTS

Sludges often result from the cleaning process due to the chemical reactions taking place. They must be periodically removed from the solution to assure its proper functioning. Process solutions are also discarded as “batch dumps” when they reach the end of their useful life, which might be daily or quarterly depending on operating conditions.

ADVANTAGES

- Solutions and parts are not flammable or explosive (aqueous systems).

- Cleans particles and film better than solvents.
- Cleans inorganic or polar material.
- Cleaning solutions are less expensive than solvents.
- Removes organic films, oils, and grease effectively.
- Allows use of multiple cleaning mechanisms (e.g., spraying, mechanical agitation).
- Reduces metal content in the waste stream (semi-aqueous systems).

DISADVANTAGES

- Cleaner residues can be difficult to rinse.
- Additional floor space may be required.
- Has a higher energy consumption than solvent cleaning.
- May require wastewater treatment prior to discharge.
- May require purified water in some applications.
- Some cleaners emit VOCs and may produce odors (semi-aqueous systems).

COMMERCIAL STATUS

Aqueous and semi-aqueous systems have been used for years and are commercially available through a number of vendors. The principal users are electroplaters, metal finishers, and electronics manufacturers.

COST AND ELECTRICAL REQUIREMENTS

For a complete cleaning and drying system, the capital cost is $10,000–$710,000 and the power requirement varies from 11–159 kW, depending on the size of the system, the complexity of controls, and the type of technology applied.

Electric IR Drying & Curing

BASIC PRINCIPLE

Infrared (IR) is part of the electromagnetic spectrum, occurring between visible light and radio waves (0.75–1000 microns). Electric IR radiation is produced by heating an emitter of IR radiation. The radiation emitted is absorbed by the substance at which it is directed, causing the molecules of the substance to vibrate and generate heat. The heat thus generated dries a coating from the inside out. IR systems require no special airflow for heat transfer because energy radiates directly to the coated surface without heating the air. By localizing the origin of the emissions, and allowing the use of reduced- or nonsolvent paints and coatings, the technology enables facilities to significantly reduce or eliminate VOC emissions.

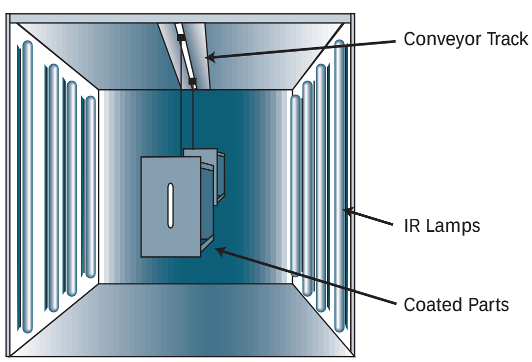
IR wavelengths are separated into three ranges: short, medium, and long. Short-wave IR provides fast, intense bursts of energy and, depending on the material, can penetrate the deepest. Short-wave IR is most useful when short cycle times are required, such as in drying inks in the printing industry and curing powder coatings in the metal finishing industry. Medium-wave IR is less intense than short-wave, thus it is more useful for heat-sensitive materials such as textiles. Medium-wave IR is also more readily absorbed by plastics and glass, and is typically used to dry water-based inks, coatings, and adhesives. Long-wave IR has the shallowest penetration and therefore heats more by convection; it is well-suited to slower, more even heating, such as is required for drying paper products and film. Long-wave IR is also less sensitive to color differences, making it the wavelength of choice for drying or curing multicolored products.

Many factors must be considered in selecting the appropriate type of IR equipment (i.e., short-, medium-, or long-wave emitters) for a given application. These factors include the absorption factor and color of the product as well as the depth of penetration and processing speed required. The absorption factor is determined by the temperature, humidity, thickness, color, and surface condition of the material being dried or cured. Each material best absorbs energy of a specific wavelength. Peak efficiencies are typically achieved by matching the wavelength of the IR emitter to the absorption wavelength of the product. For example, water has a maximum absorption of 2.6–3.2 microns, making medium-wave IR best for drying water-based materials.

SYSTEM DESCRIPTION

A typical electric IR system includes quartz lamps and reflectors. Systems are typically configured as a tunnel or bank of lamps on a

Electric Infrared Continuous Oven



process line; smaller applications use moveable arch or portable arm-mounted lamps. An IR system reaches full power in less than 1 second and can be accurately regulated with simple controls. Electric IR systems are also highly energy efficient, especially in comparison to gas IR systems. In an electric IR system, more than 85–90% of the energy used is converted to radiation, and 50–70% of the energy used is absorbed by the substance that needs drying. A gas IR system transfers only 20–25% of the energy used to the drying substance and produces emissions of its own.

KEY INPUTS

Electricity is the key input to an IR oven.

KEY OUTPUTS

There is very little output from an IR oven. However, depending on the coating material being cured, VOC emissions can result from the curing process.

ADVANTAGES

- Quick, effective curing. Reduces process time 50–80% in comparison to convective drying ovens. Curing takes place almost instantly.
- Markedly increases production potential.
- Quick startup and shutdown eliminates costly preheating, thereby increasing overall efficiency.
- Relatively insensitive to changing conditions (i.e., temperature, humidity).
- Modular design and small size of IR panels allow flexibility; they are easily incorporated into existing production lines and require minimal floor space.
- Reduced need for air circulation since IR heats products directly.
- Long lifespan, minimal maintenance.
- Relatively short payback period, depending on the application.

DISADVANTAGES

- The initial capital cost can be high.
- Has difficulty uniformly heating geometrically complex shapes.

COMMERCIAL STATUS

Long- and medium-wave IR are well-known and have been used to dry materials and/or cure coatings since the 1930s. A variety of IR source systems are available through numerous vendors. Systems can be obtained with heating element temperatures of 600–4000°F, thereby producing radiation in the 1.0–6.0-micron wavelength. However, as industry makes increased use of low- and nonsolvent paints, inks, and coatings, shortwave technology (0.75–2.3-micron wavelength) is becoming more prevalent. As evidenced by the large number of IR equipment manufacturers active in this market, many manufacturing facilities are already using short-wave IR equipment.

COST AND ELECTRICAL REQUIREMENTS

A basic electric IR spot heater or panel heater with two or three quartz emitters costs $1000–$2500. Custom-designed ovens or tunnels cost $10,000–$250,000.

Electric IR ovens typically cost 10–20% less than gas convection ovens for the same application and features. This is primarily because fewer control systems are required (e.g., air handling equipment and gas-related safety features).

Electrolysis

BASIC PRINCIPLE

Electrolysis uses an electric current to cause a chemical change in a substance in solution. "Electrowinning" is a type of electrolysis in which metal ions in solution are reduced to metals plated onto a series of cathodes. Loaded cathodes can be sold to a metal reclaimer. The process is generally used to treat spent process or rinse water prior to subsequent treatment or discharge to a publicly owned treatment works (POTW).

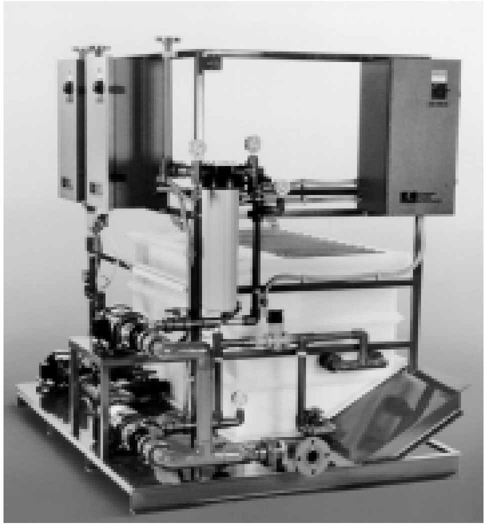
Most metal finishing facilities remove metal from wastewater through chemical precipitation and sedimentation, producing a toxic sludge that requires disposal as a hazardous waste. Electrolysis produces no sludge, thereby eliminating the cost and the potential liability associated with hazardous sludge disposal. Electrolysis is an efficient process at both high metal concentrations (process streams) and low metal concentrations (rinse streams). The only maintenance task is routine replacement of the cathodes. Electrolysis can be used to recover precious metals such as gold and silver, and other metals such as copper, brass, nickel, zinc, and cadmium.

SYSTEM DESCRIPTION

The electrochemical process strips spent plating and rinse water of dissolved metal ions by passing an electric current through the wastewater. Each electrolyte cell contains at least one anode and one cathode. Exposure to the current causes the metal ions to adhere, as solid metal, to the cathode(s).

Electrolysis can be used by itself to recycle metals from a primary rinse bath, to treat wastewater before ion exchange, or to treat the effluent produced by ion exchange regeneration. (When used prior to ion exchange, less frequent regeneration of the ion exchange unit is needed.) With electrolysis, no modifications are needed when adding a unit, although the highest efficiency is achieved when the system is installed at the static rinse bath (where up to 95% of the metals can be recovered).

One of the main advantages of electrolysis is the reduction of hazardous waste. Electrolytic cells have the ability to recover toxic heavy metals in their most valuable form—as pure metals. A second benefit is oxidation of the organic materials present in the solution (e.g., cyanide) at the anode, while recovering metal at the cathode. The most efficient electrolytic metal recovery systems—those recovering metals from rinse streams—are based on the use of high-



Electrolytic Metal Recovery System

surface-area cathodes. The high surface area results in low-operating-current density and good mixing at the cathode/liquid interface; this helps to maximize metal recovery at low metal concentrations.

Recovery efficiency also varies with metals. Some metals are not recoverable electrolytically, such as barium, titanium, and tungsten. In addition, the presence of iron or chromium, even in very low concentrations, can negatively affect the efficient recovery of metals that are ordinarily readily collected by electrowinning.

KEY INPUTS

Electrolysis uses electricity to operate and requires routine replacement of the cathodes used to capture metals from the waste stream.

KEY OUTPUTS

Electrolysis produces no sludge, thereby eliminating the costs associated with hazardous sludge disposal. Electrolysis results in waste that contains high metal concentrations that simpify the reclamation process; the wastewater, however, has low concentrations of metal, making this easier to process as well. Since cathodes must routinely be replaced, spent cathodes are another output of electrolysis.

ADVANTAGES

- Reduces the volume of hazardous waste and associated costs
- Improves rinse quality and life
- Reduces water use
- Operates efficiently at low and high metal concentrations
- Reduces both chemical and labor costs (compared to chemical precipitation)
- Destroys cyanide via oxidation
- Permits the recovery of usable metals
- Permits the regeneration of an ammoniacal or chloride etch solution during metal recovery

DISADVANTAGES

- Capital cost is high compared to chemical precipitation.
- Iron and chrome compounds in the waste stream may reduce efficiency levels.
- Some metals are not recoverable (barium, boron, titanium, and tungsten).

COMMERCIAL STATUS

Electrolysis has been used by the chloralkali and aluminum industries since 1890. Since then, new techniques have developed for electrolysis such that the process is currently being used in electroplating, metal finishing, electronics manufacturing, and photofinishing. Units are easy to add to existing metal recovery systems in order to meet strict water pretreatment standards. Units are commercially available in packages ranging from 1 square foot to more than 100 square feet of cathode surface area. Larger custom units are also available.

COST AND ELECTRICAL REQUIREMENTS

The metal concentration of the waste stream determines the recovery capacity requirement; the capacity requirement determines the system cost. The installed cost for a standard flat plate unit (used with process streams, which have high metal concentrations) depends on the cathode surface area; prices range from $15,000 for a standard-cathode system of 10 square feet to nearly $60,000 for a standard system of 100 square feet. This compares to an average price of $30,000 for a high-surface-area cathode system (used with rinse streams, which have low metal concentrations) of 175 square feet of cathode area. Costs are partially offset by annual savings from reclaiming valuable metals, reduced waste-water treatment, and reduced chemical and sludge disposal costs. The electrolytic cells represent the primary use of electricity; a circulating pump also uses some electricity. Energy requirements are highly variable and difficult to predict.

Ion Exchange

BASIC PRINCIPLE

An ion exchange unit can remove low concentrations of heavy metals from wastewater. The process employs specially charged materials, called ion exchange resins, that exchange metal ions for nonmetal ions and later release the metal ions to a regeneration solution. The resins have high removal capacities and a relatively long operating life.

Ion exchange units have several applications, including separating metals from dilute rinse waters, regenerating acid baths that contain metals, and recycling rinse water. An ion exchanger separates metal salts (metal ions) from the rinse waters of anodizing, etching, stripping, and electroplating operations. The resulting concentrated metal-acid solution (regenerate) is often treated by electrodialysis or electrolysis for solid metal or metal salt recovery. Gold, silver, copper, nickel, chromium, and zinc are among the metals that can be removed from wastewater. However, to remove more than one metal from a waste stream typically requires a resin bed for each metal.

Ion Exchange System

SYSTEM DESCRIPTION

In an ion exchange unit, metal-bearing wastewater is pumped through columns of chemically treated resin. Metal ions are removed from the wastewater and concentrated as they chemically attach to the resin, which exchanges a hydrogen or sodium ion for a metal or chemical ion. When the resin sites are filled, the resin can be regenerated with an acid solution; this solution causes the resin to reexchange a metal or chemical ion for a hydrogen or sodium ion. The metal-rich regenerate is then treated with electrolysis to recover the metal. The resin must be replaced periodically, when it can no longer be regenerated. Organic contaminants in the wastewater can lead to a loss of resin capacity.

KEY INPUTS

An ion exchange unit requires energy to operate the pumps, and chemically treated resins to capture the filtrate. In addition, if a regenerant is used to extend the life of resin columns, the regenerant and subsequent water to remove the regenerant are required.

KEY OUTPUTS

An ion exchange system produces wastewater and spent resins. Resins can be regenerated to extend their useful life. If regeneration is performed, spent regenerant is produced in the process as well as increased wastewater to flush the regenerant from the resin.

ADVANTAGES

- Extracts essentially all metal ions from relatively dilute waste streams
- Produces effluent suitable for discharge without further treatment
- Low capital and operating costs compared to other recovery technologies
- Low energy demand compared to other recovery technologies

DISADVANTAGES

- May not be capable of recycling a highly concentrated waste stream
- Requires precise operation and maintenance
- Produces metal hydroxide sludge

COMMERCIAL STATUS

Ion exchange units have been used for decades. This technology is well-established and commonly used in a variety of industries, including electronics and photofinishing, to treat heavy metal-bearing wastewater.

COST AND ELECTRICAL REQUIREMENTS

Ion exchange systems have relatively low capital and operating costs. The purchase cost depends on system size and complexity. For a small unit processing 30–480 gallons per hour, the cost is $1000–$20,000. For larger units processing 200–1800 gallons per hour, the cost is $20,000–$100,000. A fully automated system processing 14,000 gallons per day with two sets of beds has a capital cost of about $35,000. Operating costs are approximately $3500 per year, based on a 150-ppm metal waste stream.

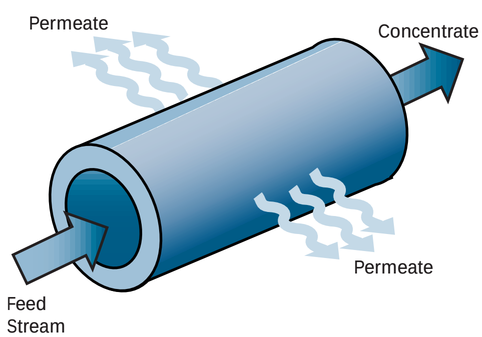
Membrane Filtration

BASIC PRINCIPLE

Membrane filtration is used by various industries to recover materials and reduce hazardous wastes and contaminants in discharge water. In this process, electrically driven pumps force wastewater through a permeable barrier that filters out selected pollutant components depending on their particle size.

Membrane separation processes include microfiltration, ultrafiltration, and reverse osmosis, and are distinguishable on the basis of the particle size filtered. Microfiltration systems have the largest pore size and capture particles from 1000–10,000 angstroms (i.e., suspended solids). Ultrafiltration systems capture particles larger than 10 angstroms—with greatest efficiency up to 1000 angstroms—which includes emulsified oil and grease, detergents, and precipitated metal hydroxides. The smallest membrane filtration systems are reverse osmosis systems, which act as a barrier to everything larger than 5–20 angstroms, including heavy metals and salts. As membrane pore size decreases, additional pressure is needed to force the wastewater through.

Membrane Filtration



SYSTEM DESCRIPTION

In membrane filtration systems, wastewater is circulated under pressure in contact with a specially constructed membrane. Water and some dissolved matter (depending on the type of membrane) passes through, while other contaminants do not. The systems are generally modular, designed as self-contained pressure vessels; microfiltration typically operates at pressures of 1–25 psi; ultrafiltration, at 10–100 psi; and reverse osmosis, at 400–800 psi. Continuous pressure is maintained by an electrically driven pump.

KEY INPUTS

Inputs for membrane filtration systems are few. The primary input is the filtration material itself.

KEY OUTPUTS

Wastewater, sludge, and spent filter material are the outputs from membrane filtration systems. The duration of filtration material is dependent on the quantity of the material to be removed from the waste stream.

ADVANTAGES

- Pollution control: Membrane filtration systems decrease the waste load, thereby reducing the amount of treatment required prior to discharge.

- Low energy requirements: Membrane filtration systems require less energy than conventional phase-change processes.
- Limited maintenance requirements: There are no moving parts, reducing the need for maintenance.
- Limited water use: Membrane filtration systems allow for recycling and reuse of the permeate by removing suspended solids.
- Modular, compact systems: The systems require less space than either evaporation or distillation processes and can be added to an existing wastewater treatment process.
- Cost savings: In general, membrane filtration systems cost a fraction of phase-change systems.
- Labor savings: Fewer person-hours are required due to reductions in materials handling and process control requirements (compared to chemical precipitation).

DISADVANTAGES

- Membrane filtration systems are susceptible to damage by a variety of inorganic and organic compounds.
- Fouling can occur when particles collect on membrane surfaces.

COMMERCIAL STATUS

Membranes have been used for over a decade to remove toxic metals and organics from wastewater. Membrane separation processes are currently used in such industries as wood preserving, electroplating, metal finishing, food processing, chemical processing, printing, and pulp and paper processing. Membrane filtration units are available from a large number of vendors nationwide; unit capacities range from 0.1 to more than 500 gallons per minute.

COST AND ELECTRICAL REQUIREMENTS

Capital and operating costs depend primarily on the type of membrane and its specific application. The purchase cost for either an ultrafiltration system or a microfiltration system for a plant processing 5 gallons per minute is about $34,000, and the operating cost is about $0.004 per gallon. A reverse osmosis system processing the same amount would cost $30,000–$35,000, and have an operating cost of about $0.003 per gallon.

Electrical requirements depend on the type of application, unit size, membrane type (pore size), waste stream temperature, pressure, and flow rates. Electricity is required for pumping water through the system. Units for small operations range in size from 0.1–10.0 gallons per minute and require 4–10 kW of electricity, respectively.

Metal Spray Coating

BASIC PRINCIPLE

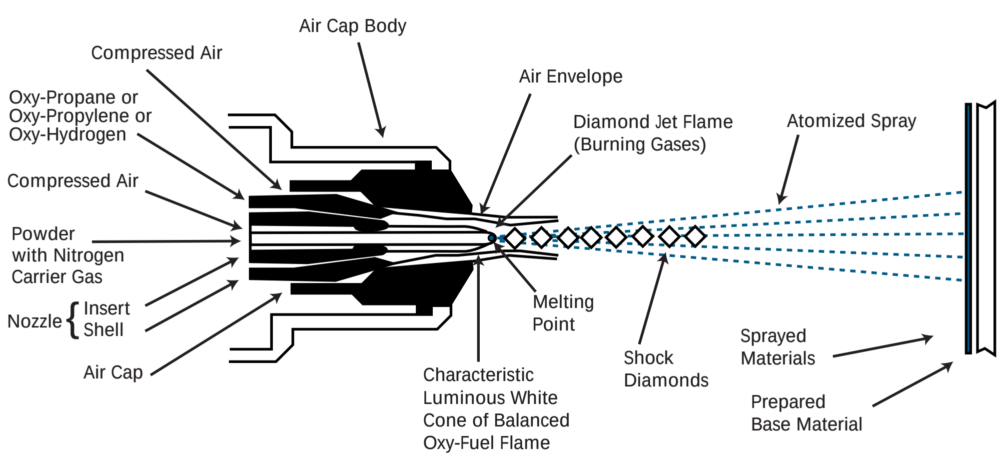
Metal spray coating (or thermal spraying) is a group of related techniques in which atomized molten metal is sprayed on a substrate with sufficient velocity to form a dense and adherent coating. The particles strike the substrate and immediately flatten to form thin platelets that bond to the substrate and to each other. The particles build up and cool into a laminar structure that forms a coating. The coating material may be in powder, rod, or wire form. The thermal spray gun uses plasma arc, combustible gases, or an electric arc to generate the heat necessary to melt the coating material.

SYSTEM DESCRIPTION

Metal spray finishing is flexible: different combinations of equipment and consumables achieve different coatings. Basic metal spray systems typically consist of a spray gun, powder supply or gas control console, and a wire or powder feeder. The individual techniques vary mainly in how the coating is melted and in the form of the coating prior to melting. The three basic means for melting the metal are as follows:

- Molten Metal—The metal is heated by either resistance heating or a burner and then supplied to the atomizing source in molten form.
- Fuel/Oxidant—Oxygen/acetylene flames melt the metal as it is continuously fed to the flame in the form of a wire or powder. The flame is surrounded by a jet of compressed air or inert gas that is used to propel the molten metal toward the substrate.
- Electric Arc—An electric arc is maintained between two wires that are continuously fed as they melt at the arc. Compressed air atomizes the molten metal at the arc and propels it toward the substrate.

Metal Spray Coating



KEY INPUTS

Most metal spray systems are electrically intensive. Melting the coating material and propelling it to the substrate require maintaining both a constant arc and a source of high gas pressure. Other inputs are the coating material in powder, rod, or wire form.

KEY OUTPUTS

The conversion efficiency of metal spray coating is not very high. Therefore, it is necessary to periodically remove excess coating materials from machinery. This results in solid waste that requires proper disposal.

ADVANTAGES

- Appropriate for a wide range of substrates (e.g., paper, plastic, glass, metals, and ceramic)
- Expands the variety of materials that can be coated with a thin metal coating (makes a range of new products possible)
- Generates little waste by avoiding use of plating solutions and associated rinses
- Coatings are extremely tough and wear-resistant

DISADVANTAGES

- High initial cost
- Limited ability to coat inside recesses or cavities

COMMERCIAL STATUS

The technologies for metal spray coating of metals are well-developed, but they tend to have their own market niche and are not typically thought of as a replacement for electroplating. As the costs of hazardous waste treatment and disposal rises, however, this family of techniques may become cost-effective replacements for coating applications currently performed by electroplating.

COST AND ELECTRICAL REQUIREMENTS

Initial cost is very high for metal spray systems. System size and purpose has a large impact on overall cost. Some systems are portable, others are fixed within a production line. Electrical consumption for metal spray processes is high. Molten metal and arc metal spray systems use the most electricity, since electricity is used to melt the metal coating before it is applied.

Physical Vapor Deposition

BASIC PRINCIPLE

Physical vapor deposition (PVD) encompasses several deposition processes in which atoms are removed by physical means from a source and deposited on a substrate. Thermal energy and ion bombardment are the methods used to convert the source materials into a vapor.

PVD makes it possible to use titanium nitride as a replacement for chromium coatings. Titanium nitride is much harder than chromium but can be cost-effectively applied in much thinner coatings. The thinner coating also has a down side of brittleness, making titanium nitride inappropriate for some applications. Titanium nitride coatings also do not provide as much corrosion protection as do thicker, crack-free chromium coatings.

PVD results in a thin, uniform coating that is much less likely to require machining after application. However, PVD is a line-of-sight coating process, and parts with complex shapes are difficult to coat.

SYSTEM DESCRIPTION

The thoroughly cleaned workpiece is held in a chamber under very high vacuum and the chamber is heated to 400–900°F, depending on the specific process. The workpiece is plasma-etched for further cleaning, and the coating metal is then forced into the gas phase by one of the three methods: evaporation, sputtering, or ion plating.

Evaporation

High-current electron beams or resistive heaters are used to evaporate material from a crucible. The evaporated material forms a cloud and then condenses onto the substrate to produce the desired film. The deposited films are not excessively adherent or dense. Deposition of a uniform coating may require complex rotation of the substrate since the vapor flux is localized and directional. Despite this, evaporation is probably the most widely used PVD process.

Sputtering

The surface of the source material is bombarded with energetic ions, usually an ionized inert gas environment such as argon. The physical erosion of atoms from the coating materials that results from this bombardment is known as sputtering. The substrate is placed to intercept the flux of displaced or sputtered atoms from the target. Although sputtering is more controllable than evaporation, it is an inefficient way to produce vapor.

Ion plating

Ion plating produces superior coatings adhesion by bombarding the substrate with energy before and during deposition. Coating atoms sputter off some of the substrate materials, resulting in a cleaner, more adherent deposit. The film grows over time because the sputtering or cleaning rate is slower than the deposition rate. High gas pressure results in a more uniform deposit on the substrate.

KEY INPUTS

PVD processes are electrically intensive and require high levels of energy. Creating vacuums, generating plasma, and operating control mechanisms all require electricity. Coating material is also a prime input.

KEY OUTPUTS

Because vaporized coating material is distributed throughout the vacuum chamber, the equipment must be scraped or stripped periodically to remove the accumulated deposits. This can create a solid or liquid wastestream that cannot be reused directly in the process and must be disposed of in some form.

ADVANTAGES

- Substrates coated with titanium nitride and other PVD coatings are not subject to hydrogen embrittlement.
- PVD allows for careful control of deposition thickness, allowing extremely thin coatings.
- PVD coatings have superior adherent qualities.

DISADVANTAGES

- High capital costs.
- System operators must be well-trained.
- Coatings applied with PVD processes are extremely thin; coatings may suffer premature wear.
- PVD is a line-of-sight process that makes it difficult to coat parts with complex shapes or recessed cavities.

COMMERCIAL STATUS

PVD-applied titanium nitride coatings have gained wide acceptance in the cutting tool industry. Such coatings are now being examined by a variety of industries, including the aerospace industry. It is expected that other coatings will be developed for the PVD process in the near future.

COST AND ELECTRICAL REQUIREMENTS

The initial equipment and installation cost is very high for a PVD system. Further research is likely to simplify the process and reduce equipment costs. Electrical consumption of all PVD processes is high. Energy use is especially high for sputtering, where costs are typically 3 to 10 times greater than those for evaporation PVD.

Powder Coating

BASIC PRINCIPLE

Powder coating is applied as a dry powder using an electrostatically charged spray gun. After application, the powder is heated to produce a paint-like coating. Powders have four basic elements: resins, pigments, extenders, and additives. The resins provide the base for the pigment; extenders add properties such as edge covering and minimize cost; additives produce other effects, such as reduced cure time or higher gloss.

Powder manufacturers can customize blends to provide powders for almost every application—any color or gloss range, many textures and thicknesses. In powder manufacture, the components are mixed, ground, melted, remixed, extruded, and broken into powder.

SYSTEM DESCRIPTION

The electrostatic application process of powder coating includes “fluidization” of the powder by means of a controlled air supply through a membrane in a hopper. The spray gun is then set for proper air, spray pattern, and electrical charge. When properly set, the electrically charged powder particles are then sprayed to the grounded part or product.

For powder to achieve the properties for which it was formulated (decorative, visual, chemical, mechanical), time and temperature must be accurately controlled. The cure time is composed of two stages, the “bring up” time and the “dwell” time. The bring up time is the time it takes for the metal (substrate) to reach the desired temperature. The dwell time is the time required for the powder to cure properly.

There are three basic ways of heating the parts to the temperature required to cure the powder: convection (heat transmitted by air circulation), radiation/ infrared (heat transmitted to the part only), and induction (heat transmitted by inducing electrical current).

The powder goes through four stages during the oven cycle to cure correctly: melting, flowing, gelling, and curing. Too much or too little oven time affects finish quality. Finish quality is also determined by factors such as cleanliness (dust, dirt, oil, moisture, etc.), process testing, and equipment maintenance.

The final phase of the process is allowing the part to cool; a part that is still hot mars easily.

KEY INPUTS

The primary input for a powder coating system is the powder itself. There is little waste due to the electrostatic application process. In addition, over-spray powder can be collected and reused.

KEY OUTPUTS

One major benefit of powder coating systems is that they produce very low levels of VOC emissions. Little powder is wasted since overspray can be collected and reused. Cleaning powder coating equipment is difficult and produces wastewater. This is especially true if a system is being cleaned to spray another color. Purging the system of all old powder is difficult and requires cleaning agents.

ADVANTAGES

- Produces negligible volatile organic compound (VOC) emissions
- Does not require elaborate and expensive spray booth air evacuation and waste management systems
- Application is often simpler than wet-spray technologies, making operator knowledge less critical

DISADVANTAGES

- A powder must be used as-is. It is not possible to “tweak” the formula to attain different qualities.
- All curing occurs at once; it is not possible to produce clean breaks between colors by masking.
- More cleanup time is required in comparison to painting—to clean a spray booth, application gun, and reclaim system.

COMMERCIAL STATUS

Although powder coating systems have been available for years, the process continues to grow in popularity. Systems of all sizes are available, from simple hand-operated units for small, infrequent production runs to fully automated systems using conveyer systems for transporting parts through the process of coating and curing.

COST AND ELECTRICAL REQUIREMENTS

The initial cost of a powder coating system is quite competitive with fluid coating techniques. A small-scale powder coating system can be installed for less than $100,000; the cost of a production-scale powder coating line can easily exceed $500,000.

Powder coating systems require energy for application and curing. Electricity is used in the application process to both charge parts electostatically and to propel the powder through the gun. However, the total consumption of electricity is not great. The curing process uses the most energy. Curing ovens are either fueled by natural gas or by electrically generated infrared (IR) radiation. Facilities that produce a constant high-volume flow of parts typically use thermal ovens fueled by natural gas. For shops with smaller production volumes or with intermittent production requirements, electric IR ovens are more advantageous.

Ultrasonic Cleaning

BASIC PRINCIPLE

The phaseout of many chlorofluorocarbons (CFCs) by the Clean Air Act Amendments of 1990 is forcing the metal finishing industry to look for CFC-free methods for cleaning parts. One alternative technology is ultrasonic cleaning, which meets environmental regulations and achieves a higher standard of cleanliness and better production efficiency than traditional CFC-based methods.

Ultrasonic cleaning uses high-frequency sound waves to cavitate a liquid. The cavitation releases stored energy and provides scrubbing and cleansing action in the form of localized high pressures (nearly 10,000 psi) and high temperatures (nearly 2000°F) at the site of implosion. However, because the pressure and temperature are localized, the entire cleaning tank does not experience these conditions. Although the energy released by one implosion is small, the combined energy of millions of cavitation bubbles can effectively clean metal parts.

SYSTEM DESCRIPTION

Ultrasonic cleaning can be used with a variety of solvents and aqueous and semi-aqueous solutions. The selection of a solvent or solution should be determined by the characteristics of the soil to be removed. Alkaline aqueous solutions are preferred over most solvents for environmental reasons and for their ability to clean most metals and metal alloys well. Aqueous and semi-aqueous solutions are also typically less expensive and are easier to use, since boiling and vapor recovery are not necessary; however, the solutions must be heated to a specific temperature, depending on the type of soil. Solvents are still the best option for removing heavy grease and oil.

Ultrasonic cleaning requires three key pieces of equipment: a cleaning solution tank, an electric generator, and a transducer. The solution tank can be any size and is typically stainless steel; larger tanks require larger generators. The electric generator

Ultrasonic Parts Cleaning System

supplies electricity to the transducer, which converts the electricity to sound waves in the 20–40 kHz range.

KEY INPUTS

The inputs depend on the solution used in the ultrasonic cleaning tank. Ultrasonic cleaning is usually performed with aqueous cleaning solutions. The ultrasonic device itself is simply a solid-state transmitter of high frequency waves and requires only electricity to power it.

KEY OUTPUTS

Since ultrasonic cleaning is a wet process and depends on a cleaning solutions, wastewater is a by-product of the process. Liquid wastes contain materials removed from the parts during cleaning. This often includes solvents, oils, and other solid materials common to manufacturing processes.

ADVANTAGES

- Effective cleaning: Cleans parts more effectively than manual wipe cleaning, mechanical agitation, or spray washing.
- Reduced emissions: Reduces or eliminates CFCs and emissions of volatile organic compounds.
- Reduced process time: Cleans parts in a fraction of the time of wipe cleaning.
- Less expensive chemicals: Replaces expensive solvents with less-expensive alkaline solutions or water.
- Reduced cleaning chemicals: Requires fewer aqueous solution chemicals.
- Increased safety: Employees can avoid direct contact with toxic chemicals.
- Adaptable: Batch or in-line operation are possible.

DISADVANTAGE

- Limited application: Not effective in all applications, and some chemicals can harm the substrate.

COMMERCIAL STATUS

Ultrasonics were first used by the U.S. Navy in World War II to detect enemy submarines. The technology has since expanded into hundreds of applications. In the metal finishing and electronics industries, ultrasonic cleaning technology has been used for over 20 years. As a result, ultrasonic cleaning equipment is widely available from a variety of vendors.

COST AND ELECTRICAL REQUIREMENTS

Small, single-tank ultrasonic systems cost $3000–$8000. Multistage ultrasonic systems (systems involving more than one tank for cleaning and/or rinsing) cost $35,000–$80,000, depending on unit characteristics. Dryers, deionized water rinses, or oil-coalescing equipment can add to the system cost. For some applications, ultrasonic equipment can be added to existing tanks, thereby reducing the capital cost.

Ultrasonic equipment uses 1–20 kW of electric power for a typical small application. Depending on the degree of automation and peripheral equipment used, additional power may be necessary. For an 80-gallon system, the power requirement is about 18 kW; 6 kW issued to generate the ultrasonic energy and 12 kW to heat the solution.

BASIC PRINCIPLE

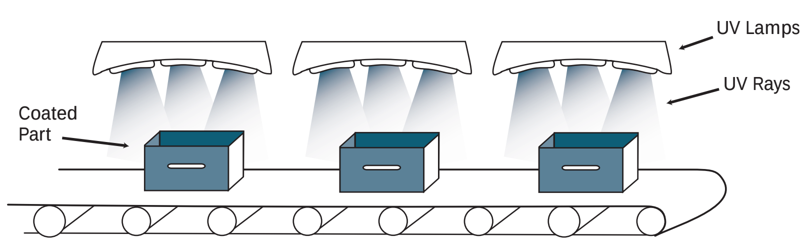
Ultraviolet (UV) radiation has a wavelength range of 4–400 nanometers. UV radiation can be used to cure inks or coatings containing polymers that cross-link when subjected to radiation. The cross-linking transforms the coating from a liquid to a solid. Radiation-curable coatings provide a clear or pigmented finish that protects, decorates, and provides other functional properties.

Curing differs from drying in that drying is accomplished by driving off a solvent, usually through evaporation, leaving the pigment or coating material on the surface of the product. Only solvent-containing inks or coatings can be dried. Curing, on the other hand, changes the molecular structure of the coating material to solidify it. Radiation-curable coatings, therefore, do not need to contain organic solvents and eliminate the problem of volatile organic compound (VOC) emissions.

SYSTEM DESCRIPTION

Two basic types of lamps are commonly used to produce UV light: medium-pressure mercury vapor lamps (arc lamps) and medium-pressure mercury microwave-powered lamps (microwave-powered or electrodeless lamps). In both cases, the UV energy produced by the lamp bulb is focused by reflectors onto the coated materials as they move down a process line. The UV energy striking the materials causes a photoinitiator (a chemical in the coating) to trigger the cross-linking reaction, curing the coating. The UV light must be enclosed to prevent worker exposure.

Most UV systems are custom-made for use with conveyor-driven process lines. By using multiple lamps, the width of the treatment area can be extended as needed. Lamp length determines the number of lamps needed to achieve a specific treatment-area width. System price varies with type, number, and length of lamps; type of shielding; and cooling method. The capital cost of a conventional curing system, such as a gas-fired curing oven, can be nearly four times greater than that of an equivalent UV curing system. Also, although radiation-curable inks or coatings are twice as expensive per pound as conventional solvent-based coatings, less coating material is used per



unit. The process is also easy to control; so there is less loss of product due to poor quality, and costs become comparable.

KEY INPUTS

Electricity is the key input to an UV curing oven.

KEY OUTPUTS

There is very little output from a UV oven. However, depending on the coating material being cured, AMPLATE emissions can result from the curing process.

ADVANTAGES

- Radiation-curable inks and coatings dry quickly, thereby increasing the production rate.
- UV systems work with nonsolvent coatings, thus eliminating VOC emission concerns.
- Since no VOC emissions occur, UV curing eliminates the need for VOC incinerators.
- UV curing equipment takes 10–50% less space than conventional fuel-fired curing ovens.
- Radiation-curable coatings are available in an array of colors and provide a high-gloss finish with improved wear- and scratch-resistance.

DISADVANTAGES

- Ozone can form if the UV light reacts with available oxygen.
- Operating personnel must avoid the hazards of exposure to UV light.

COMMERCIAL STATUS

UV curing is currently used in a variety of industrial applications where a clean or very thin coating is required and where acceptable radiation-curable coatings are available. Examples include printing labels, decorating metal, hardening polymers on nonwax flooring materials, and coating printed circuit boards with protective insulation.

UV systems are readily available for a range of applications. Small systems with one or two lamps are frequently used in laboratories and in manufacturing plants for testing ink coatings and adhesives before application to film, foil, or paper substrates. Medium-sized systems with multiple lamps are used to cure finishes on metal, glass, and plastic products. Large multichambered ovens with rows of lamps are used to cure finishes on floor tiles and on textured coatings on large substrates such as paper, board, or glass. More complex UV systems are used in curing coatings on products that are not flat, such as wires, tubes, furniture, packaging, and electronic assemblies.

COST AND ELECTRICAL REQUIREMENTS

The cost of UV curing systems vary significantly with size and system complexity. A single-lamp system may cost a few hundred dollars, while a complex multilamp system may cost hundreds of thousands of dollars. The majority of UV curing systems are custom-made multilamp systems; their price depends on the type and number of lamps, type of shielding, and cooling method.

An arm-mounted UV system for new installation or retrofit to an existing system usually costs $1000–$5500 and consumes 120–600 watts per inch, depending on the number of lamps and lamp length. A fully automatic UV lamp conveyor system costs $8000–$60,000 and consumes 200–800 watts per inch, depending on the complexity of controls and lamp lengths.

Vacuum Evaporation

BASIC PRINCIPLE

Vacuum evaporation technology vaporizes wastewater at temperatures below the boiling point of water (212°F). The water and chemicals can then be separated without the chemical degradation that can occur with vaporization at higher temperatures. The water can be recovered for reuse or disposal. The concentrated liquid left in the vacuum chamber can be sent to a filter press for further dewatering, or to the plating tank for reuse. This process reduces the residual waste to a fraction of the amount produced with conventional wastewater treatment technology, allowing the recycling of water and chemicals and reducing disposal costs.

SYSTEM DESCRIPTION

In a metal finishing facility, solution chemicals are dragged from plating tanks or parts-cleaning baths into rinse tanks. With vacuum evaporation, the chemical-bearing rinse water is pumped into a vacuum chamber, where the wastewater is vaporized at temperatures as low as 110°F. The vapor rises through a mist separator where particulate matter is removed. A cooling coil causes the steam to condense, and distilled water forms in the reservoir and can be

Vacuum Evaporation Unit

returned to the rinse tank for reuse. As the water is driven off, dissolved metal salts concentrate in the effluent. This valuable liquid is collected and returned to the plating or other process tank. Because of the low temperatures, degradation of heat-sensitive plating chemicals is held to a minimum. This process can recover many plating chemicals and detergents; metals such as chrome, nickel, copper, cadmium, brass, zinc, silver, and gold; alkalies and acids; and industrial wastewater.

KEY INPUTS

Vacuum evaporation equipment is quite sensitive and, if misused or monitored incorrectly, is costly to repair. Fouling of the filtration mechanism can require extensive replacement of parts.

KEY OUTPUTS

Wastewater is minimized using a vacuum evaporative process. Most wastewater from vacuum evaporative systems can be recovered for reuse, depending on the toxicity and concentration of the suspended metals. Recoverable metals are also a by-product of this process.

ADVANTAGES

- All rinse water can be recycled.
- No fumes or odors are produced.
- Nearly complete recovery of metal waste.
- Low-temperature operation.
- Can be operated on a continuous discharge basis.
- Reduces operating costs by recovering/recycling metals, solutions, and water.
- Reduces the amount of sludge requiring disposal.
- Requires minimal space.

DISADVANTAGES

- Potential buildup of condensing organics requires periodic cleaning.
- High initial investment.
- The residual waste can contain traces of hazardous materials and requires proper disposal.

COMMERCIAL STATUS

Ion exchange and electrolysis are mature waste stream recovery technologies now in common use. Vacuum evaporation nearly completely eliminates water discharge from metal finishing facilities and, therefore, may be adopted widely in the future if pretreatment standards tighten further. Vacuum evaporation units are commercially available from a number of companies nationwide in capacities ranging from 0.6–3000 gallons of wastewater per hour. One manufacturer has an automatic recirculating system in which aqueous effluent is continuously introduced into the evaporation chamber.

COST AND ELECTRICAL REQUIREMENTS

Vacuum evaporation has low operating costs (as low as $0.01 per gallon), requires no operating chemicals, and generates few residual chemicals and/or sludge, while also minimizing water use. The payback period is typically 3 months to 1 year.

The small units typically used by metal finishing operations process 0.01–1.0 gallon per minute and have a power draw of 1.5–20.0 kW, respectively. The primary electricity user is the vacuum pump; the secondary user is the recirculating pump. Most small vacuum evaporation units cost $7000–$28,000, with larger units reaching costs of $154,000.

b

Equipment Suppliers

AQUEOUS & SEMI-AQUEOUS CLEANING

American Metal Wash
360 Euclid Ave.
Canonsburg, PA 15317
(724) 746-4203
fax: (724) 746-5738
www.amwclean.com

CD Nelson Manufacturing Company
26920 N. Grace Ave.
Wauconda, IL 60084
(847) 487-4870
fax: (847) 487-4873

Electrovert Corp.
1111 W. North Carrier Pkwy., Suite 200
Grand Prairie, TX 75050
(214) 606-1900

Forward Technology Industries, Inc.
13500 County Rd. 6
Minneapolis, MN 55441
(612) 559-1785
fax: (612) 559-3929
www.forwardtech.com

Gray Mills Corp.
3705 N. Lincoln Ave.
Chicago, IL 60613
(312) 248-6825

Jensen Fabricating Engineers
555 Wethersfield Rd.
Berlin, CT 06037
(860) 828-6516
fax: (860) 828-0473
www.jenfab.com

Lewis Corp.
102 Willenbrock Rd.
Oxford, CT 06478
(203) 264-3100
fax: (203) 264-3102

Ramco Equipment Corp.
32 Montgomery St.
Hillside, NJ 07205
(908) 687-6700
fax: (908) 687-0653
www.ramkleen.com

CAE Ransohoff Inc.
4933 Provident Dr.
Cincinnati, OH 45246
(800) 248-9274
(513) 870-0100
fax: (513) 870-0105
www.caeransohoff.com

SAS, Inc.
2435 N. Indian Hill Blvd.
Claremont, CA 91711
(909) 624-0396
fax: (909) 624-6336

SONICOR Instrument Corp.
100 Wartburg Ave.
Copiague, NY 11726
(800) 864-5022
(516) 842-3344
fax: (516) 842-3389
www.sonicor.com

Sonitech, Inc.
239 East Stephenson St.
Freeport, IL 61032
(815) 235-2400
fax: (815) 232-2150

Stoelting, Inc.
502 Highway 67
P.O. Box 127
Kiel, WI 53042
(920) 894-2293
fax: (920) 894-7029
www.stoelting.com

Tally Cleaning Systems
Division of Metfab Engineering
332 John Diestch Blvd.
Attleboro Falls, MA 02763
(508) 695-1007
fax: (508) 695-6335
www.metfabeng.com

Unique Industries
P.O. Box 417
Derby, CT 06418
(203) 735-8751
fax: (203) 736-0906

U.S. Polychemical Corp.
584 Chestnut Ridge Rd.
Chestnut Ridge, NY 10977
(914) 356-5530
(800) 431-2072
fax: (914) 356-6656
www.uspoly.com

ELECTRIC IR DRYING & CURING

Aitken Products, Inc.
566 North Eagle St.
Geneva, OH 44041
(440) 466-5711
fax: (440) 466-5716

Americure, Inc.
2353 W. Lincoln St.
Phoenix, AZ 85009
(602) 253-3130

Argus International
P.O. Box 38-M
Hopewell, NJ 08525
(609) 466-1677
fax: (609) 466-4111

BGK
4131 Pheasant Ridge Dr., N.E.
Minneapolis, MN 55449
(612) 784-0466
fax: (612) 784-1362

Cleveland Process Corp.
127 S.W. Fifth Ave.
Homestead, FL 33030
(800) 241-0412
fax: (305) 248-4371

Dry-Clime Corp.
P.O. Box 146
State Rd. 46 W.
Greensburg, IN 47240
(812) 663-4141
fax: (812) 663-4202

Edwin Trisk Systems
670 New York St.
Memphis, TN 38104
(800) 261-7976
fax: (901) 274-8355
www.trisk.co.uk

Eraser Company, Inc.
Olivia Dr.
P.O. Box 4961
Syracuse, NY 13221
(800) 724-0594
(315) 454-3237
fax: (315) 454-3090
www.eraser.com

Future Cure
29313 Clemins
Westlake, OH 44145
(800) 722-4664
fax: (216) 835-1578

Fostoria Industries, Inc.
1200 N. Main St.
Fostoria, OH 44830
(419) 435-9201
fax: (419) 435-0842
www.etven.com/fostoria

Glenro, Inc.
39 McBride Ave.
Paterson, NJ 07501
(800) 922-0106
fax: (201) 279-9103
www.glenro.thomasregister.com

Infratech Corp.
1634 Industrial Park St.
Covina, CA 91722
(818) 331-9400

Infratrol Manufacturing Corp.
646 S. 29th St.
Milwaukee, WI 53234
(414) 671-7140
fax: (414) 671-5088
www.infratrol.com

IRT System
89 Connie Crescent
Concord, Ontario
L4K 1L3, Canada
(800) 387-3639
fax: (905) 669-1171
www.irtsystem.com

Prime Heat
1946 John Towers
El Cajon, CA 92020
(619) 449-6623
fax: (619) 449-9844

Process Thermal Dynamics
304 G 50th Ave.
Alexandria, MN 56308
(612) 762-2077
fax: (612) 762-1319

Radiant Energy Systems
48797 West Rd.
Wixom, MI 48393
(248) 348-1771
fax: (248) 348-0162
www.radiant-energy.com

Solaronics
704 Woodward
Rochester, MI 48307
(800) 223-5335
(810) 651-5333
fax: (810) 651-0357
www.solaronicsusa.com

Tech Systems
1030 N. Lincoln St.
Greensburg, IN 47240
(812) 663-4720
fax: (812) 663-4799

Watlow Electric Manufacturing Co.
12001 Lackland Rd.
St. Louis, MO 63146
(314) 878-4600
fax: (314) 878-6814
www.watlow.com

ELECTROLYSIS

Andco Environmental Processes, Inc.
595 Commerce Dr.
Buffalo, NY 14228
(716) 691-2100
fax: (716) 691-2880

Electrosynthesis Co.
72 Ward Rd.
Lancaster, NY 14086
(716) 684-0513
fax: (716) 684-0511

Hallmark Refining Corp.
1743 Cedardale Rd.
Mt. Vernon, WA 98273
(800) 255-1895
fax: (360) 424-8118
www.hallmarkrefining.com

Kinetico Engineered Systems, Inc.
10845 Kinsman Rd.
Newbury, OH 44065
(800) 633-5530
fax: (216) 564-1988

Manchester Corp.
280 Ayers Rd.
P.O. Box 317
Harvard, MA 01451
(508) 772-2900
fax: (508) 772-7731

Memtek Corp.
28 Cook St.
Billerica, MA 01821
(508) 667-2828
fax: (508) 667-1731

Safety-Kleen
4357 Park Rd.
Benicia, CA 94510
(707) 748-1960

ION EXCHANGE

Aquapure Technologies, Inc.
2224 E. 14 Mile Rd.
Warren, MI 48092
(800) 728-1041
fax: (810) 795-0420
www.aqua-tech-inc.com

Kinetico Engineered Systems, Inc.
10845 Kinsman Rd.
Newbury, OH 44065
(800) 633-5530
(216) 564-5397
fax: (216) 338-8694
www.kinetico.com

Memtek Corp.
28 Cook St.
Billerica, MA 01821
(508) 667-2828
fax: (508) 667-1731

Osmonics
5951 Clearwater Dr.
Minnetonka, MN 55343
(800) 355-9950
(612) 933-2277
fax: (612) 933-0141
www.osmonics.com

Serfilco, Ltd.
1777 Shermer Rd.
Northbrook, IL 60062
(800) 323-5431
(708) 559-1777
fax: (708) 559-1141
www.serfilco.com

U.S. Filter Corp.
10 Technology Dr.
Lowell, MA 01851
(800) 466-7872
fax: (508) 970-2465

MEMBRANE FILTRATION

Applied Membranes, Inc.
110 Bosstick Blvd.
San Marcos, CA 92069
(800) 727-3711
(619) 727-3711
fax: (619) 727-4427
www.appliedmembranes.com

EPOC
3065 North Sunnyside
Fresno, CA 93727
(209) 291-8144
fax: (209) 291-4926
www.epoc.com

Infinitex
P.O. Box 409
Clarence Center, NY 14032
(716) 741-8381
fax: (716) 741-9649

Koch Membrane Systems, Inc.
10 State Ave., Suite 205
St. Charles, IL 60174
(630) 513-0550
fax: (630) 513-0551
www.kochmembrane.com

544 E. Eisenhower Parkway
Suite 150
Ann Arbor, MI 48108
(734) 761-3836
fax: (734) 761-3844
www.kochmembrane.com

Komline-Sanderson
12 Holland Ave.
Petack, NJ 07977
(800) 225-5457
(908) 234-1000
fax: (908) 234-9487

LCI Corp.
P.O. Box 16348
Charlotte, NC 28297
(704) 394-8341
fax: (704) 393-8590

Membrex, Inc.
155 Route 46 West
Fairfield, NJ 07004
(201) 575-8388
fax: (201) 575-7011
www.membrex.com

Memtek Corp.
28 Cook St.
Billerica, MA 01821
(508) 667-2828
fax: (508) 667-1731

Osmonics, Inc.
59951 Clearwater Dr.
Minetonka, MN 55343
(800) 355-9950
(612) 933-2277
fax: (612) 933-0141
www.osmonics.com

Prosys Corp.
187 Billerica Rd.
Chelmsford, MA 01824
(508) 250-4940
fax: (508) 250-4977
www.prosyscorp.com

Sanborn
9 Industrial Park Rd.
Midway, MA 02053
(508) 533-8800
fax: (508) 533-1440

U.S. Filter
181 Thorn Hill Rd.
Warrendale, PA 15086
(412) 772-0044
fax: (412) 772-1360

4669 Shepard Trail
Rockford, IL 61105
(815) 877-3041
fax: (815) 877-0946

METAL SPRAY COATING

Englehard Corp.
12 Thompson Rd.
E. Windsor, CT 06088
(860) 623-9901
fax: (860) 623-4657

Flame Spray Coating Co. Inc.
33847 Doreka
Fraser, MI 48028
(810) 293-8600
fax: (810) 293-8607

Hardface Alloys, Inc.
8351 Secura Way
Santa Fe Springs, CA 90670
(310) 945-5477
fax: (310) 696-1868

High Velocity Technologies Inc.
21 Technology Dr.
W. Lebanon, NH 03784
(603) 298-5400
fax: (603) 298-5454

Metal Spraying Corp.
3600 W. Pierce St.
Milwaukee, WI 53215
(414) 645-7550
fax: (414) 645-7553

Plasma Coatings Inc. (PCI)
758 East Main St.
Waterbury, CT 06702
(203) 757-8747
fax: (203) 753-2604

Praxair Thermal Spray Products
1555 Main St.
Indianapolis, IN 46224
(317) 240-2650
fax: (317) 240-2225

Sandia National Laboratories
Thermal Spray Research
P.O. Box 5800, M.S. 1130
Albuquerque, NM 87185-1130
(505) 845-3256
fax: (505) 844-6611

PHYSICAL VAPOR DEPOSITION

A-Vac Industries
1845 South Lewis St.
Anaheim, CA 92805
(714) 938-1300
fax: (714) 938-0899
www.avac.com

Cooke Vacuum Products
13 Merit Place
South Norwalk, CT
(203) 853-9500
fax: (203) 838-9553

CVC Products, Inc.
525 Lee Rd.
Rochester, NY 14606
(716) 458-2550
fax: (716) 458-0424
1-800-448-5900
www.cvc.com

Galileo Vacuum Systems, Inc.
P.O. Box 1158
East Granby, CT 06026
(860) 653-5911
fax: (860) 653-6540
www.galileovacuum.com

Industrial Vacuum Engineering
307 N. Amphlett
San Mateo, CA 94401
(650) 348-2866
fax: (650) 348-2869

Thermionics Laboratory, Inc.
P.O. Box 3711
Hayward, CA 94540
(800) 962-2310
(510) 538-3304
fax: (510) 538-2889

General Vacuum Equipment
9800N Southern Pine Blvd.
Charlotte, NC 28273
(704) 561-7333
fax: (704) 561-7321
www.generalvacuum.com

Midwest Tungsten Services, Inc.
7101 S. Adams St. #6
Willowbrook, IL 60521
(800) 626-0226
(630) 325-1001
fax: (630) 325-3571

Sierra Technology Group, Inc.
6776-F Preston Ave.
Livermore, CA 94550
(800) 760-3003
(510) 373-4886
fax: (510) 373-4887

Deposition Sciences, Inc.
386 Tesconi Ct.
Santa Rosa, CA 95401
(800) 231-7390
(707) 573-6700
fax: (707) 579-0731
www.heatbuster.com

Sputtered Films, Inc.
320 Nopal St.
Santa Barbara, CA 93103
(805) 963-9651
fax: (805) 963-2959

POWDER COATING

Akzo Nobel Coatings, Inc.
1915 Industrial Ave.
Zion, IL 60099
(847) 872-1000
fax: (847) 872-1470

Belco Industries, Inc.
115 E. Main St.
Belding, MI 48809
(616) 794-0410
fax: (616) 794-3424

Binks Sames Corp.
9201 W. Belmont Ave.
Franklin Park, IL 60131
(847) 671-3000
fax: (847) 671-1471

H.B. Fuller Company
Industrial Coatings Division
2900 Granada Ln.
Oakdale, MN 55128
(651) 236-3733
fax: (651) 236-3535

Iontech Corp.
4815 Para Dr.
Cincinnati, OH 45237
(513) 641-3100
fax: (513) 641-3560

ITW BGK Finishing Systems
4131 Pheasant Ridge Dr., NE
Minneapolis, MN 55449
(612) 784-0466
fax: (612) 784-1362

PPG Industries, Inc.
19699 Progress Dr.
Strongsville, OH 44136
(440) 572-2800
fax: (440) 572-0848

Wagner Systems
700 High Grove Blvd.
Glendale Heights, IL 60139-9998
(630) 924-2400
fax: (630) 924-2419

SUPERCRITICAL FLUID CLEANING

Marc Sims SFE
1012 Grayson St., Suite A
Berkeley, CA 94710
(510) 843-1306
fax: (510) 843-4308
www.simssfe.com

Supercritical Fluid Technologies, Inc.
One Innovation Way, Suite 302H
Newark, DE 19711

ULTRASONIC CLEANING

CAE Blackstone, Inc.
9 North Main St.
Jamestown, NY 14701
(800) 766-6606
(716) 665-2340
fax: (716) 665-2480
www.caeblackstone.com

Blue Wave Ultrasonics
Division of Alpheus Cleaning Tech. Corp.
960 S. Rolff St.
Davenport, IA 52802
(800) 373-0144
(319) 322-0144
fax: (319) 322-7180
www.bluewaveinc.com

Branson Ultrasonics Corp.
41 Eagle Rd.
Danbury, CT 06813
(203) 796-0400
fax: (203) 796-0320

C.D. Nelson Manufacturing Company
26920 N. Grace Ave.
Wauconda, IL 60084
(847) 487-4870
fax: (847) 487-4873

Crest Ultrasonics Corp.
Scotch Rd.
Mercer County Airport
P.O. Box 7266
Trenton, NJ 08628
(800) 441-9675
(609) 883-4000
fax: (609) 883-6452

Forward Technology Industries, Inc.
13500 County Rd. 6
Minneapolis, MN 55441
(612) 559-1785
fax: (612) 559-3929
www.forwardtech.com

Lewis Corp.
102 Willenbrock Rd.
Oxford, CT 06478
(203) 264-3100
fax: (203) 264-3102

Ramco Equipment Corp.
32 Montgomery St.
Hillside, NJ 07205
(908) 687-6700
fax: (908) 687-0653
www.ramkleen.com

CAE Ransohoff, Inc.
4933 Provident Dr.
Cincinnati, OH 45246
(800) 248-9274
(513) 870-0100
fax: (513) 870-0105
www.caeransohoff.com

SAS, Inc.
2435 N. Indian Hill Blvd.
Claremont, CA 91711
(909) 624-0396
fax: (909) 624-6336

SONICOR Instrument Corp.
100 Wartburg Ave.
Copiague, NY 11726
(800) 864-5022
(516) 842-3344
fax: (516) 842-3389
www.sonicor.com

Sonitech, Inc.
239 East Stephenson St.
Freeport, IL 61032
(815) 235-2400
fax: (815) 232-2150

Tally Cleaning Systems
Division of Metfab Engineering
332 John Diestch Blvd.
Attleboro Falls, MA 02763
(508) 695-1007
fax: (508) 695-6335
www.metfabeng.com

U.S. Polychemical Corp.
584 Chestnut Ridge Rd.
Chestnut Ridge, NY 10977
(800) 431-2072
(914) 356-5530
fax: (914) 356-6656
www.uspoly.com

ULTRAVIOLET CURING

American Ultraviolet Company
562 Central Ave.
Murray Hill, NJ 07974
(908) 665-2211
fax: (908) 665-9523

Argus International
424 Route 31 North
Irngoes, NJ 08551
(609) 466-1677
fax: (609) 466-4111

Canrad Hanovia, Inc.
100 Chestnut St.
Newark, NJ 07105
(201) 589-4300
fax: (201) 589-4430

Fusion UV Systems, Inc.
910 Clopper Rd.
Gaithersburg, MD 20878
(301) 527-2660
fax: (301) 527-2661
www.fusionuv.com

Industrial Heating & Finishing Company
P.O. Box 129
Pelham, AL 35124
(205) 663-9595
fax: (205) 663-9608

Werner Lemnermann
Specialty Coating Systems
5707 West Minnesota St.
Indianapolis, IN 46241
(800) 356-8260
fax: (317) 240-2073

UV III Systems, Inc.
21 Governor Ave.
Bellingham, MA 02019
(800) 398-5456
(508) 883-4881
fax: (508) 376-4748

XENON Corp.
20 Commerce Way
Woburn, MA 01801
(800) XENON-XL
(781) 938-3594
fax: (781) 933-8804
www.xenon-corp.com

VACUUM EVAPORATION

Calfran International, Inc.
P.O. Box 269
Springfield, MA 01101
(413) 732-3616
fax: (413) 732-9246

QVC Process Systems, Inc.
35 West William St.
Corning, NY 14830
(607) 936-2500/2516
fax: (607) 936-1192

Roilgard, Inc.
5600 Thirteenth St.
Menominee, MI 49858
(906) 863-4401
fax: (906) 863-5889

Technotreat Corp.
5800 W. 68th St.
Tulsa, OK 74131
(918) 445-0996
fax: (918) 445-0994

C Trade & Other Associations

TRADE ASSOCIATIONS

American Electroplaters and Surface Finishers Society, Inc. (AESF)
12644 Research Pkwy.
Orlando, FL 32826
(407) 281-6441
fax: (407) 281-6446
www.aesf.com

Members are surface finishing professionals and those who provide services, supplies, and support to the industry.

Association for Finishing Processes
One SME Dr.
P.O. Box 930
Dearborne, MI 48121
(313) 271-1500

Chemical Coaters Association International
P.O. Box 54316
Cincinnati, OH 45254
www.finishing.com/CCAI/index.html

The finishing industry's educational and networking association.

Electrocoat Association
Cincinnati, OH
(800) 950-8977
(513) 527-8977
fax: (513) 527-8950
www.electrocoat.org

An industry group formed to promote the use of electrocoating and communicate the economic and environmental benefits of electrocoating technology to manufacturers, consumers, and the government.

Metal Finishing Association of Southern California (MFASC)
5000 Van Nuys Blvd.
Suite 305
Sherman Oaks, CA 91403
(818) 986-8393
fax: (818) 995-0878
www.mfasc.org

Affiliated with the National Association of Metal Finishers. MFASC represents custom and job shop metal finishers and serves to disseminate information on industry trends and changes.

Metal Finishing Suppliers' Association (MFSA)
112-J Elden St.
Herndon, VA 20170
(703) 709-5729
fax: (703) 709-1036
www.mfsa.org

An international organization of the major suppliers of processes, supplies, chemicals, and equipment for electroplating and other finishing needs. MFSA member companies also supply technology, consulting services, and provide laboratory and environmental services.

National Association of Metal Finishers (NAMF)
112-J Elden St.
Herndon, VA 20170
(703) 709-8299
fax: (703) 709-1036
www.namf.org

Serves suppliers and vendors to the metal finishing industry. Members are management executives, including owners of metal finishing and related businesses.

National Paint and Coatings Association, Inc. (NPCA)
1500 Rhode Island Ave., N.W.
Washington, DC 2005
(314) 462-6272
www.paint.org

A voluntary, nonprofit trade association, NPCA represents some 500 paint and coatings manufacturers, raw material suppliers, and distributors.

Powder Coating Institute (PCI)
2121 Eisenhower Ave.
Suite 401
Alexandria, VA 22314
(800) 988-COAT
(703) 684-1770
fax: (703) 684-1771
www.powdercoating.org/

Represents the powder coating industry, promotes powder coating technology, and communicates the benefits of powder coating to manufacturers, consumers, and government.

Society of Manufacturing Engineers for Finishing Processes
One SME Dr.
P.O. Box 930
Dearborne, MI 48121
(313) 271-1500 ext. 544

Society of Vacuum Coaters
71 Pinon Hill Pl. NE
Albuquerque, NM 87122
Phone: (505) 856-7188
fax: (505) 856-6716
www.svc.org

Disseminates knowledge, experience, and techniques to the vacuum coating (i.e., physical vapor deposition) industry through a variety of forums.

OTHER ASSOCIATIONS/ ORGANIZATIONS

CAGE
www.cage.rti.org

CAGE (Coatings Alternative Guide) is a tool developed by the Research Triangle Institute to assist companies or technical assistance providers in selecting appropriate alternative coatings or coatings equipment.

US EPA Envirosense
www.epa.gov/envirosense

Envirosense is one of the largest and most inclusive Web sites for pollution prevention information. Its features include a pollution prevention forum for all levels of government, researchers, industry, and public interest groups.

U.S. EPA Pollution Prevention Information Clearinghouse
401 M St., SW MC 7409
Washington, DC 20460
(202) 260-1023

The EPA's Pollution Prevention Information Clearinghouse is dedicated to reducing or eliminating industrial pollutants through technology transfer, education, and public awareness.

Finishing.com: The Home Page of the Finishing Industry
www.finishing.com

This site provides information about surface finishing from anodizing to powder coating.

Metal Finishing: The Online Finishers Resource
www.Metal-Finishing.com

This site is sponsored by a number of organizations and offers users a variety of references including lists of vendors and suppliers to the metal finishing industry.

National Metal Finishing Resource Center
www.nmfrc.org

The Center offers pollution prevention and compliance assistance information, and serves as a forum for information exchange.

Northeast Waste Management Officials' Association (NEWMOA) Clearinghouse
129 Portland St., 6th Floor
Boston, MA 02114
(617) 367-8558

NEWMOA's mission is to help states promote and implement economically sound regional programs for the enhancement of environmental protection.

P2 Gems
www.turi.org/P2GEMS

P2 is a search tool for facility planners, engineers, managers, and technical assistance providers looking for technical process and materials management information.

Pacific Northwest Pollution Prevention Research Center
1326 Fifth Ave., Ste 650
Seattle, WA 98101
(206) 223-1151
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Provides technology reviews for manufacturers, researchers, and others interested in the details of new cleaning and finishing technologies.

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d Resource List

EPRI PUBLICATIONS

This list provides EPRI resources that relate to the subject of this guide. Copies of most publications can be ordered through the EPRI Distribution Center, (925) 934-4212 or via EPRI's members-only Web site, www.EPRIweb.com.

Assessing the Performance of Powder Coating Curing Systems, EPRI CMF 93-3 (1993). Order from the Center for Materials Fabrication, (614) 421-3440.

Electroplating, EPRI TC-107893 (1997).

Electrotechnologies for Wastewater Recovery in Metals Finishing, EPRI TC-102573-V7P2 (1991).

Guidebook of Environmental Solutions for Small Businesses, EPRI TR-102843 (1993).

Infrared Curing of Powdered Coatings, EPRI TA-102572-V4P1 (1990).

Plating, Finishing, and Coating: State-of-the Art Assessment, EPRI EM-4569 (1986).

Powder Power: Bonding Success with Infrared Heat, EPRI SU-107536 (1997).

A Small-Business Guide: Metal Finishing, EPRI TR-106676-V6 (1997).

Strategies for Marketing Electrotechnologies and Energy Services to Small Businesses: Metal Finishers & Electronics Fabricators, EPRI TR-109134 (1997).

Ultrasonic Assisted Cleaning, EPRI TC-102982-V9P1 (1993).

The following application screening guides are available through EPRI's Small Business Solutions Target. For information, contact the EPRI Project Manager, Jim Kuegle, at (650) 855-2879 or e-mail jkuegle@epri.com.

- Aqueous Cleaning
- Electric Drying of Parts
- Infrared Curing of Coatings on Metal
- Membrane Filtration of Parts Cleaning Solution
- Ultrasonic Cleaning

Application screening guides can be used to identify potential technology applications and other process improvements at specific customer locations, to estimate the new technology cost and payback period, and to calculate the potential change in load. A series of questions and calculation formulas are provided to determine the potential impacts of a new electrotechnology on a customer's business.

GUIDE RESOURCES

The following publications provided source material for this guide.

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Cushnie, G.C. Jr. *Pollution Prevention & Control Technology for Plating Operations, first edition,* National Center for Manufacturing Sciences, Ann Arbor, MI (1994).

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Industrial Technology Institute. "Customized Benchmarking Report: Metal Finishing; Generic Metal Finishers, AnyTown, USA," Ann Arbor, MI (1995).

Northeast Waste Management Officials' Association. *Pollution Prevention for the Metal Finishing Industry: A Manual for Pollution Prevention Technical Assistance Providers*, Boston, MA (1998).

——. *Pollution Prevention in Metal Painting and Coating Operations: A Manual for Technical Assistance Providers*, Boston, MA (1997).

"Overview Articles on Finishing Processes," *Plating and Surface Finishing*, journal of the American Platers and Surface Finishers Society (August 1997).

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Surface Finishing Market Research Board. *Metal Finishing Industry Market Survey, 1992–1993*, Metal Finishing Suppliers' Association and National Association of Metal Finishers (1994).

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The following Web sites also provided source material for this guide.

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www.ctc.com (metal finishing technologies), Concurrent Technologies Corporation, Johnstown, PA (1998).

www.powdercoat.com (powder coating information), Paul Crea, H.B. Fuller Company, Oakdale, MN (1998).

www.sandia.org.gov/materials/sciences/Capabilities/CO2_Cleaning (supercritical carbon dioxide cleaning), Sandia National Laboratories, Albuquerque, NM (1998).

www.svc.org (vacuum coating information), Donald Mattox, Society of Vacuum Coaters, Albuquerque, NM (1998).

Glossary

This glossary is exerpted from two publications of the Northeast Waste Management Officials' Association (NEWMOA): *Pollution Prevention for the Metal Finishing Industry: A Manual for Pollution Prevention Technical Assistance Providers* and *Pollution Prevention in Metal Painting and Coating Operations: A Manual for Technical Assistance Providers*; both were published by NEWMOA in February 1997.

acid descaling
An alternative name for "pickling," a process using acid to dissolve oxide and scale.

acid
Chemical substance whose water solutions exhibit a pH less than 7.

activation
Process of removing last trace of oxide on a metal surface and a thin layer of tile metal itself to ensure that the metal surface to be plated is electrochemically active (see "etching").

additives
Any substance added in small quantities to another substance, usually to improve properties. Examples of additives include plasticizers, fungicides, and dryers.

air knife
A slotted jet of compressed air quickly blows superfluous water from parts, often before they enter a dry off oven.

air spray
A paint spray application system using air at high velocity and pressure to atomize the paint.

air turbine
1) Electric motor-driven fans that create volumes of relatively low-pressure atomizing air for spraying. Their output is referred to as turbine air; 2) An air-driven precision fan that is used to spin a paint atomizing disk or bell head.

air-assisted airless spray
Paint spray application system using fluid pressure to atomize the paint and low pressure air to adjust the shape of the fan pattern.

air-dried coatings
Coatings that are not heated above 194ºF (90ºC) for coating or drying. In the South Coast Air Quality Management District, curing also must be done below (rather than at or below) 194ºF (90ºC) to qualify as air dried. Air-dried coatings also include forced-air dried coatings.

air dryers

Used to remove moisture from compressed air. Dryers have three basic styles of operation: 1) Deliquescent types have disposable drying agents and tend to be marginally effective for painting; 2) Refrigerated dryers cool the air to condense and remove the water. Most paint systems use this type; 3) Desiccant types have a double-bed dryer and are able to achieve the lowest dew point air. The beds are alternately on-stream and back-flushed to regenerate their moisture absorbing qualities. Some plants with critical finish requirements use this style of dryer to reach dew points of -40ºF.

airless spray

A paint spray application system using high fluid pressure to atomize paint by forcing it through a small orifice.

alkali

Any substance that neutralizes acids. Alkalis are helpful in aqueous cleaning to speed soil removal and suspension. Alkali is synonymous with caustic.

alkaline descaling

A chemical process for removing scale. A typical descaling solution uses caustic soda with additives shell as detergents and chelating agents.

alkyd

A binder based on resins formed by the condensation of polyhydric alcohols with polybasic acids. They may be regarded as complex polyesters (Thermoset).

alloying

The addition of one metal to another metal or nonmetal or combinations of metals. For instance, steel is an alloy of carbon and iron. Other metals are added to steels to impart specific characteristics like strength or corrosion resistance.

amalgamating

Process in which alloys are formed, with mercury such as gold, silver, iron, copper and aluminum. Due to the toxicity of mercury, use of the technique is declining.

amino resins

Resins used to cross-link polyesters, epoxies, acrylics, and alkyds to enhance their durability.

amorphous

Structure that is noncrystalline or without a regular structure.

amperes (AMPS)

An electrodynamic unit of measure for the quantity of current in a steady electric flow.

annealing

A heat treatment process, which may be applied to all metals to soften them.

anode

The positive electrode in electrolysis, at which negative and positive ions are discharged, positive ions are formed, or other oxidizing reactions occur.

anodic coating

A protective, decorative, or functional coating formed by conversion of the surface of a metal in an electrolytic oxidation process.

anodic etching

A form of electrolytic etching where the workpiece is being etched is anodic in the electrolytic circuit (in electroplating, the workpiece is the cathode).

anodizing

A process generally applied to aluminum and its alloys to produce an adherent oxide film to impart corrosion resistance or surface hardness.

aquablast
A surface cleaning process that can be applied to any material where all abrasive material is suspended in water. The resulting slurry is pressurized and ejected through a nozzle.

aromatic solvents
Hydrocarbon solvents that contain an unsaturated ring of carbon atoms, including benzene, naphthalene, anthracene, and their derivatives. These solvents are characterized as volatile organic compounds.

atomization
The formation of tiny liquid droplets during the spraying of coatings.

autodeposition
Dip coating application method that depends on a chemical reaction to plate out the coating film.

baked coatings
Coatings that are cured or dried at or above an oven air temperature of 194ºF (90ºC).

barrel plating (or cleaning)
Plating or cleaning in which the work is processed in bulk in a rotating container.

base metal
A metal that readily oxidizes or dissolves to form ions. The opposite of a base metal.

bells
A rotating head that is shaped to deliver paint forward in a circular pattern. The bell may be directed at any angle and be moved on robots or reciprocators, just as spray guns are.

binder
The solid (nonvolatile) material in a coating that binds the pigment and additive particles together to form a film. Most binders are resins.

blocking
Undesirable sticking together of painted surfaces when pressed together under normal conditions. Sticking or blocking can be reduced by antiblock paint additives.

blooming
Powder-like deposit forming on the surface of the film often resulting from partial dissolving and redepositing of pigment by a solvent component.

borax treatment
A method of coating steel with a thin film of dry lubricant. Alkaline coating imparts lubrication for subsequent drawing operations and provides minor corrosion protection.

boriding
A high temperature process used for surface hardening of mild low carbon steels.

bounce-off, bounceback
Paint droplets from air-atomized application that rebound or bounce away from the surface due to the blasting effect of the air.

bright chrome plating
Decorative chromium plate deposited directly on a nickel plate substrate.

bright dip
A solution used to produce a bright surface on a metal.

brightener
An addition agent that increases the brightness of the deposit.

bronzing
A chemical process generally applied to steel to impart the appearance of bronze. The "bronze" film does not have the corrosion resistance of true bronze.

building up
Electroplating for the purpose of increasing the dimensions of an article.

bulk coating
The painting of large masses of small unchangeable parts by a variety of possible techniques such as dip-spin and dipping.

burnishing
A form of metal finishing where the surface is treated mechanically so that no appreciable metal is removed but the surface is smoothed.

burnt deposit
A rough or otherwise unsatisfactory deposit produced by the application of an excessive current density and unusually containing oxides or other inclusions.

case hardening
A family of surface hardening processes generally applied oily to steels (e.g., carbonitriding, carburizing, chromium plating, cyanide hardening, electroless nickel plating, and nitriding).

casting
A general term covering a production technique where any metal is heated until it is molten and then poured into a mold, allowed to cool and solidify.

cathode
The negative electrode in electrolysis at which positive ions are discharged, negative ions are formed, or other reducing actions occur.

cathodic etching
A technique applied to steel workpieces using sulfuric acid with a cathode to create an electrolyte. The anode will generally be lead or stainless steel. When a current is applied, the surface metal oxide will be reduced. The technique is usually applied immediately prior to electroplating.

cathodic protection
A technique applied to steel where metals anodic to iron (e.g., zinc, aluminum, magnesium) are applied to the surface on the steel workpiece to provide a corrosion-resistant surface.

cation
A positively charged ion.

caustic
A substance that neutralizes acids. Caustics are used in aqueous cleaning to speed soil removal and increase soil suspension. Caustic is synonymous with alkali.

checking
Slight breaks in the film that do not penetrate to the substrate surface. If the substrate surface is exposed it is called cracking.

chemical polishing
A process carried out oil mild- and low-alloy steel, stainless steel, aluminum. Special solutions are used to attack the surfaces of these metals in such a manner that the peaks or corners are affected in preference to the concave surfaces. The result is a general smoothing of the surface.

chlorinated solvents
Organic solvents that contain chlorine. These solvents are characterized as VOCs. Their use is regulated and heavily restricted.

chromate coating (chromating)
A corrosion protection technique that has many variations and can be applied to steel, aluminum, magnesium, and zinc. It results in the formation of metal oxide on the surface of the workpiece, which reacts to form metallic chromates.

chromium plating
This electrodeposition of chromium is generally applied to steel in all its forms. It is usually done for decorative purpose (bright chromium) or to provide a hard surface for engineering purposes (hard chromium). Chromium plate is nearly always deposited on top of a nickel deposit. The nickel deposit supplies corrosion resistance.

chromizing
A treatment applied to mild- and low-alloy steel only. It is a surface diffusion process in which chromium is alloyed with iron to create a chromium-rich surface layer.

coating line
Coating lines are all operations involved in the application, and/or drying of surface coatings.

coating
A liquid or mastic composition that is converted to a solid protective, decorative, or functional adherent film. A material that is applied to a surface and that forms a continuous film in order to beautify and/or protect the surface.

cold galvanizing
A term sometimes used to differentiate between electroplating zinc on steel from the hot dipping of steel in molten zinc. The purpose is to provide corrosion resistance.

color anodizing
A process used only on aluminum and its alloys using dyes to color the anodic film. The anodic process produces a porous film which, when fresh, will absorb dyes.

coloring
The production of desired colors onto a workpiece using chemical or electrochemical action

complexing agent
A compound that will combine with metallic ions to form soluble ions.

contact plating
Deposition of a metal with the use of an internal source current by immersion of the work in solution in contact with another metal.

continuous coater
An enclosed automatic spray booth that recovers and reuses oversprayed paint. A continuous coater is suitable for coating large volumes of similarly sized parts.

conversion coating
A chemical or electrochemical treatment of a metal surface to convert it to another form, which provides an insulating barrier of exceedingly low solubility between the metal and its environment, and is an integral part of the metallic substrate. Examples are phosphate coating of steel and zinc and chromate anodizing of aluminum.

corrosion
Corrosion occurs in all metals at some time and can be divided into four basic forms. Room temperature oxidation, the most common form, is most obvious in mild and low-alloy steels. The process is accelerated dramatically by comparatively small amounts of contaminants like chloride, sulfate, and fluoride.

cosolvents
Water-miscible organic solvents. Waterborne paints frequently require cosolvents in addition to water for easier manufacturing and improved application properties.

covering power
The ability of a plating solution, under a specified set of plating conditions, to deposit metal on the surfaces of recesses or deep holes (to be distinguished from throwing power).

cracking
The splitting of a dry paint film, usually the result of aging. This includes hair cracking, checking, crazing, and alligatoring (crocodiling).

cratering
Small round depressions in a paint film that may or may not expose the underlying surface.

crawling
A defect in wet paint or varnish film where it recedes from small areas of the surface, leaving them apparently uncoated. Crawling is caused by an incompatible film on the surface.

crazing
The formation of fine surface cracks, often as a network, which do not penetrate to the underlying surface.

cross-linking
The setting up of chemical links between the molecular chains of a resin to form a three-dimensional network polymer system. Cross linking generally toughens and stiffens coatings.

cure
Using heat, radiation, or reaction with chemical additives to change the properties of a polymeric system into a more stable, usable condition. For liquid coatings, it is the process by which the liquid is converted into a solid film.

current density
A measure of the total electrical flow across a given area, frequently expressed in units of amps/square foot.

deionized water
Water resulting from the removal of contaminants by a double-bed ion exchanger. Deionized water is comparable in purity to distilled water but is much less costly to produce.

deposit
Refers to the metal coating deposited on the workpiece.

descaling
A process that can be applied to all materials to remove scale. Scale is generally produced during manufacture or storage. Various methods are used for this process, including blasting, pickling, acid or alkaline sodium hydride treatments, and polishing.

die-casting
A method of casting in which molten metal is poured, sometimes under pressure, into a mold or die. The die is made of metal and immediately after solidification of the casting the die opens and the casting is ejected.

diffusion coating
An alloy coating produced by applying heat to one or more metal coatings deposited on a metal.

dip coating
The process in which a substrate is immersed in a solution (or dispersion) containing the coating material and withdrawn.

dip-spin coater
Bulk painting of small and unchangeable parts accomplished by dipping a mesh basket of parts, followed by rapid rotation of the basket to remove excess paint.

disks (discs)
Rotating heads that deliver paint using a horizontal 360 degrees motion and an omega loop conveyer line. A disk is usually mounted horizontally on a vertical reciprocator.

dispersion coating
A type of coating in which the binder molecules are present as colloidal particles and spread uniformly throughout the formulation as a stable mixture.

distribution
Refers to the uniformity of the metal deposited from a plating process.

dragin
The water or solution that adheres to workpieces introduced into a bath.

dragout
The solution that adheres to a workpiece removed from a bath.

drier
An additive that accelerates the drying of coatings.

ductility
Refers to the flexibility of an electroplated deposit; this parameter is critical when bending and forming operations occur after plating.

dummy (dummy cathode)
A cathode in a plating solution that is not to be used after plating; often used for removal or decomposition of impurities.

E-coating (electrodeposition)
A dip coating application method where the paint solids are given an electrical charge opposite to the part being coated. In this method, which closely parallels electroplating, paint is deposited using direct electrical current.

electrocleaning
An electrochemical cleaning process by which a workpiece is first made the cathode in an electrolytic cell. When current is applied, the generation of hydrogen gas from the electrolysis of water at the surface of the workpiece results in a highly efficient scrubbing action.

electrode potential
The difference in potential between an electrode and the immediately adjacent electrolyte.

electrode
A conductor through which current enters or leaves an electrolytic cell at which there is a change from conduction by electrons to conduction by charged particles of matter or vice versa.

electroforming
A specific form of electroplating used where intricate shapes and relatively thin metal deposits are required. Molds of plastic, wax, or sometimes metals are made conductive by application of carbon or metallic powder and are plated by conventional methods.

electrolysis
Production of chemical changes by the passage of current through an electrolyte.

electrolyte
A conducting medium in which the flow of current is accompanied by movement of matter; most often an aqueous solution of acids, bases, or salts, but includes many other media such as fused salts, ionized gases, and some solids.

electrolytic etch
A technique generally applied to steels that attack the surface to produce a clean, oxide free material. It is often used prior to electroplating.

electrolytic polishing
An electrochemical process usually applied to steels, aluminum, and aluminum alloys.

This process produces a surface that is bright and highly reflective.

electroplating
The process of depositing metal from an aqueous solution using an external potential (electrical current) for the metal cation reduction process; usually, the potential applied is dc, but can approach controlled ac with some sophisticated switching devices (pulsed electroplating).

electrostatic spray
Method of spray application of coating where an electrostatic potential is created between the part to be coated and the paint particles.

electrowinning
The production of metals by electrolysis with insoluble anodes in solutions derived from ores or other materials.

emulsion
A two-phase liquid system in which small droplets of one liquid (the internal phase) are immiscible in, and are dispersed uniformly throughout, a second continuous liquid phase (the external phase).

enamels
Topcoats that are characterized by their ability to form a smooth surface. All paints, powder or liquid, that form cross-linking chemical bonds during curing are considered enamels. The majority of industrial finishes fall into this category.

epoxies
Binders based on epoxy resins. Epoxy cross-linking is based on the reaction of the epoxide groups with other materials such as amines, alcohols, phenols, carboxylic acids, and unsaturated compounds.

etching
Etching is sometimes used as a surface preparation technique prior to electroplating or for removal of metal such as in the printed circuit industry where material not required on the finished product is removed by a chemical solution. It can also be used as an inspection technique due to its ability to accentuate surface cracks and defects.

film
One or more layers of coating covering an object or surface.

filtration
A means of separation where constituents are separated, usually by physical methods.

fisheye
A paint defect resulting in a pattern of small surface depressions or craters in the wet film, often caused by surface contamination such as oil or silicone materials.

flash point
The lowest temperature of a liquid at which it gives off sufficient vapor to form an ignitable mixture with air.

flash-off time
The time required between application of wet-on-wet coatings or between application and baking to allow the bulk of the solvents to evaporate.

flocculation
The combination or aggregation of suspended colloidal particles in such a way that they form small clumps; usually used in conjunction with additive chemicals (flocculants) to treat wastewater.

flow coating
A coating application system where paint flows over the part and the excess coating drains back into a collection system.

fluidized bed
Finely divided powders can be made into a fluid-like state by passing air through the porous plate bottom of a powder hopper. This permits its powder particles to be used in dip tanks and to be transported in a manner similar to liquids.

fluxing
A process used in the heating of metals that may be intended to reduce or eliminate oxidation, confine the products of oxidation, reduce their melting point, and improve fluidity of surface metal layers.

fouling
Deposition of materials on a membrane surface or within the pores because of soluability limits (at the surface) or pore size and/or shape.

fusion
The melting of a powder coating into a solid film.

galvanizing
A corrosion-protection technique applied only to mild steel, cast iron, and steel alloys. Galvanized coatings are generally about 0.005 inches thick and can give protection for 10 to 20 years.

ground (electrical ground)
An object so massive that it can lose or gain overwhelmingly large numbers of electrons without becoming perceptibly charged.

halogenated hydrocarbons (halogenated solvents)
Formed by substituting one of the halogen elements (chlorine, bromine, or fluorine) into a chemical compound to change both the physical and chemical nature of the compound.

hard chromium
Chromium plate for engineering rather than decorative applications; not necessarily harder than the latter, but generally thicker or heavier. See "chromium plating."

HCD (high current density)
High amperes per surface area.

heat-resistant coatings
Designed to resist degradation upon continuous or intermittent exposures to a predetermined elevated temperature.

high-temperature coatings
Coatings certified to withstand a temperature of 1000ºF for 24 hours.

high-solids
Solvent-borne coatings that contain greater than 50% solids by volume or greater than 62% (69% for baked coatings) solids by weight.

hot dip coating
See "galvanizing."

hydrocarbon solvent
An organic compound consisting exclusively of the elements carbon and hydrogen. They are principally derived from petroleum and coal tar, and include aliphatic, aromatic, and napthenic solvents.

hydroxides
The chemical opposites of acids. Also known as caustics and alkalis. Examples are sodium hydroxide and potassium hydroxide.

immersion plating
A plating technique similar to electroless plating where a more electropositive metal is dissolved in an electrolyte and is plated onto the surface of a less electronegative metal workpiece. The term immersion plating is used where a deposit is obtained and the

plating process then stops—unlike electroless plating where the deposition of the metal being plated continues to deposit as long as the workpiece remains in the solution.

indicator (pH)

A substance that changes color when the pH of the medium is changed; in the case of most useful indicators, the pH range within which the color changes is narrow.

inhibitor

A chemical additive that retards undesired chemical reactions such as corrosion, oxidation, drying, and skinning.

initiator

A chemical used to help start a chemical reaction such as polymerization. Its action is similar to that of a catalyst, except that it is usually consumed in the reaction.

inorganic polymers

Substances whose principal structural features are made up of homopolar interlinkages between multivalent elements other than carbon. Examples of such polymers are ethyl and butyl silicates, mica, clays, and talc.

ion exchange

A reversible process by which ions are interchanged between a solid and a liquid with no substantial structural changes in the solid.

ion

An electrified portion of matter having atomic or molecular dimensions.

lacquer

Coating composition based on synthetic thermoplastic film-forming material dissolved in organic solvent and dried primarily by solvent evaporation. Typical lacquers include those based on nitrocellulose, other cellulose derivatives, vinyl resins, and acrylic resins.

latent solvent

A liquid that cannot itself dissolve a binder but that increases the tolerance of the coating for a diluent.

latex

Stable dispersion of polymeric solids in an aqueous medium.

LCD (low current density)

Low amperes per surface area.

lead plating

Lead plating does not have many common uses except lithe production of electrodes for lead-acid batteries.

mandrel

A form used as a cathode in electroforming; a mold or matrix.

mechanical plating

The application of an adherent metallic coating by mechanical means involving the compacting of finely divided particles of such metal to form coherent coatings.

membrane

A microporous structure that acts as a highly efficient filter that allows passage of water, but rejects suspended solids and colloidals; depending on membrane type, ions and small molecules might or might not be rejected.

metal spraying

The general term is applied to the spraying of one of several metals onto a metal substrate. In general, it is intended to produce three effects: 1) Corrosion protection; usually involves the spraying of zinc or aluminum. 2) Hard facing; materials used are tungsten bearing or tungsten carbide materials, cobalt, nickel with chromium, and manganese chrome. 3) Salvaging; worn components can be re-surfaced to replace the wear.

noble metal
A metal that does not readily tend to furnish ions and, therefore, does not readily dissolve nor easily enter into such reactions as oxidations; the opposite of a base metal.

overspray
Any portion of a spray-applied coating that does not land on a part.

oxygenated solvents
Volatile organic compounds that contain oxygen in addition to carbon and hydrogen. Includes alcohols, esters, ketones, and ether-alcohols.

passivation
The cleaning of stainless steel with nitric acid to remove carbon and other impurities.

permeate
The output from ultrafiltration; also called ultrafiltrate.

phosphating
A pretreatment for steel or certain other metal surfaces by chemical solutions containing metal phosphates and phosphoric acid as the main ingredients. A thin, inert adherent, corrosion-inhibiting phosphate layer forms that serves as a good base for subsequent paint coats.

pickling
A chemical treatment that removes oxide or scale from the surface of a metal. It most often refers to the use of sulfuric or hydrochloric acid to remove scale formed on mild and low-alloy steel during hot forming operations.

plating
An electroplating or electroless plating process.

polymers
A high molecular weight organic compound, natural or synthetic, with a structure that can be represented by a repeated small unit.

pot life
The length of time a coating material is useable after the original package is opened or after a catalyst or other ingredient is added.

powder coatings
Any coating applied as a dry (without solvent or other carrier), finely divided solid that adheres to the substrate as a continuous film when melted and fused.

primers
Coatings that are designed for application to a surface to provide a firm bond between the substrate and subsequent coatings.

rack plating
A frame for suspending and carrying current to articles during plating and related operations.

reflowing
A technique used in the printed circuit board industry in which a component is heated in order to melt solder deposits and causing them to flow. It produces a bright, attractive-looking material, but its main purpose is for quality control. With reflowing, any defect on the substrate will not get wet, clearly indicating areas where solder is missing.

resin
The polymer (plastic) component of a paint that cures to form a paint film. Also known as binder or vehicle.

retarders
Solvents added to a coating to slow down a chemical or physical change, such as the rate of evaporation.

reverse osmosis
In reverse osmosis, high pressures are applied to force water out of the concentrated solution, often to obtain pure (or purer) water. Solvent is driven through a semipermeable membrane separating solutions of different concentrations.

roll coating
Process by which a film is applied mechanically to sheet or strip material.

rustproofing
A general term that refers to processes applied to steel. It can include painting or galvanizing, but most often refers to phosphating and similar low-duty rust preventatives.

sacrificial protection
A corrosion-protection technique that uses a metal of lower electrode potential to protect a metal of higher electrode potential. The anode corrodes and deposits onto the surface of the cathode. In practice, zinc and aluminum are the two metals most commonly used for this process.

sealers
A liquid coat applied to a porous substrate such as wood or plaster, to prevent tile substrate from absorbing subsequent coatings.

sealing or anodic coating
A term commonly applied to any metal process having a subsequent treatment capable of affecting a previous process coating in order to reduce staining and corrosion of the workpiece or to improve the durability of color of the coating.

silicones
Resins consisting of silicon-oxygen linkages, unlike organic resins, which contain carbon.

solder plating
The term covers deposition of an alloy of 60% tin and 40% lead that is widely used in the electric and electronics industries. It provides two valuable features, corrosion resistance and “solderability.”

solution paint
Resin molecules fully dissolved by solvents in the paint.

solvency
The degree to which a solvent holds a resin or other paint binder in solution.

solvent-borne
Coatings in which volatile organic compounds are the major solvent or dispersant.

strike
1) A thin film of metal to be followed by other coatings. 2) To plate for a short time, usually at a high initial current density.

substrate
Surface material or electroplate upon which a subsequent electrodeposit or finish is made.

surface hardening
A general term referring to methods for making the surface of steel workpieces mechanically harder than their inner portions.

thermoplastic
Resin capable of being repeatedly softened by heat and hardened by cooling. These materials, when heated, undergo a substantial physical, rather than chemical, change. Thermoplastic resins can be completely dissolved with appropriate solvents.

thermoset
Resin that, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble material. Thermosetting resins will soften but will not dissolve in any solvent.

topcoat
The final coating film or multiple layers of the same coating film applied to the surface.

transfer efficiency
The ratio of solids adhering to a surface to the total amount of coating solids used in the application process, expressed as a percentage.

ultrafiltration
The process that uses membranes to achieve separation of various constituents; a typical ultrafiltration membrane allows water, ions, and small molecules to pass through while rejecting large molecules and suspended solids.

ultrasonic cleaning
Vibrational frequencies slightly higher than those audible used to agitate immersion cleaning tanks. Microbubble formation in the liquid accelerates dislodgement of soils.

undercoats
Coatings formulated and applied to substrates to provide a smooth surface for subsequent coats.

urethanes
Materials based on resins made by the condensation of organic isocyanates with compounds or resins containing hydroxyl groups.

vacuum deposition
A process in which certain pure metals are deposited on a substrate. The technique relies on the fact that, in a vacuum, pure metals can be vaporized at a low temperature in a closed container. The metal vapor will condense evenly on all surfaces to produce a metallic coating. Aluminum is the most successfully deposited material, producing a highly reflective finish.

vacuum metallizing
Process in which surfaces are thinly coated by exposing them to metal vapor under a vacuum.

vapor deposition
1) Chemical—a process for producing a deposit by chemical reaction, induced by heat or gaseous reduction of a vapor condensing on the substrate. 2) Physical—a process for depositing a coating by evaporating and subsequently condensing an element or compound, usually in a high vacuum.

volatility
The tendency of a liquid to evaporate. Liquids with high boiling points have low volatility and vice versa.

wetting agent
A substance that reduces the surface tension of a liquid, causing it to spread more readily on a solid surface without it beading up.

wrap around
Electrostatic effect where charged coating particles curve around the part and are deposited onto the rear side of the part.

Target:
Small Business Solutions

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