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A small-business guide

## **Metal Finishing**

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# REPORT SUMMARY

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Many of the challenges faced by small business owners can be addressed through efficient use of electric technology. Each volume in the Small Business Guide describes the current state of a business type and details new or alternative electric equipment that can help it meet its characteristic problems.

## **Background**

Members of the small-business community historically have had little contact with their energy providers. These guides were developed to facilitate communication between electric utilities and the small businesses in their communities.

## **Objective**

To provide utility personnel and small business owners and operators with information on the key electrotechnologies that can help these businesses compete effectively.

## **Approach**

The project team researched small business energy, productivity, and environmental concerns and the electrotechnologies that can meet these needs. Telephone surveys, published reports, directories, buyers guides, and technical journals provided information on technology availability, suppliers, information sources and trade associations.

## **Results**

The Small-Business Guide series covers a range of industries:

Volume 1: Wholesale Bakeries

Volume 2: Auto Body Shops

Volume 3: Lodging

Volume 4: Medical Clinics

Volume 5: Drycleaners and Launderers

Volume 6: Metal Finishers

Volume 7: Shopping Centers

Volume 8: Convenience and Grocery Stores

Each guide is based on extensive and ongoing research and contains the latest information available at the time of publication. The guides have been organized as a reference document for use on an as-needed basis. Section tabs are included to facilitate quick access to topics of interest; and each volume concludes with lists of equipment suppliers, EPRI information resources, and trade organizations.

### **EPRI Perspective**

The EPRI Small Businesses target is dedicated to research, development, and dissemination of information on electrotechnologies that address the energy, productivity, and environmental concerns of small business owners and operators. Future volumes in the Small Business series will cover

- Printers
- Office Buildings
- Electronics
- Apparel manufacturers
- Photofinishers
- Plastic products
- Wood preservers
- Wood furniture

### **TR-106676, Volumes 1-8**

#### **Interest Categories**

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Appliances

#### **Key Words**

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Lighting  
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Wayne Krill manages the Small Businesses Target at EPRI and directed development of the *Guide*.



## ABOUT THIS GUIDE

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Members of the small-business community historically have had little contact with their energy providers. This guide was developed to facilitate communication between electric utilities and the metal finishing shops and/or operations in their communities.

The *Metal Finishing* guide is intended to familiarize readers with the business of metal finishing by providing descriptions of basic processes and practices and summaries of the key challenges faced by metal finishers. It focuses on delineating how electric equipment can address the needs and interests of metal finishing business owners and operators.

This business guide is one of a series of publications about small businesses produced by the Electric Power Research Institute (EPRI). The *Metal Finishing* guide is based on extensive and ongoing research and contains the latest information available at the time of publication. Nevertheless, it is a work in progress rather than a definitive and final document. The information and resources presented offer the reader a solid base from which to develop electricity-based solutions to energy and business needs.

This guide is organized as a reference document for use on an as-needed basis. Section tabs are included to facilitate quick access to topics of interest; icons representing energy end uses are also provided to help with locating complete information on electrotechnology solutions.





Metal finishing is a highly diverse industry, involved in the manufacture of everything from paper clips to disk drives, diamond rings to army tanks. It is also a highly competitive industry characterized by small, highly specialized shops, typically located in proximity to the manufacturing firms that utilize their products.

In 1992, independent metal finishing “job shops” sold over \$11 billion in goods, but netted only 5% profit. In the years to come, profits could decrease further as businesses in this chemical-intensive industry install new equipment to meet regulatory requirements governing airborne and waterborne releases of toxic wastes. Under this pressure, some shops will fold or merge because they do not have the capital both to upgrade process equipment to meet customers’ needs as well as to purchase the emissions control equipment necessitated by law. Other job shops may follow their manufacturer customers overseas, where labor rates are lower and profits may be larger.

To prevail against these challenges, metal finishers are striving to invest judiciously in new processes or chemistries that will provide their shops a safe market niche while simultaneously reducing operating costs and complying with environmental regulations. The accompanying table identifies electrotechnologies that can help metal finishing shops to reduce costs, improve productivity, and/or expand product variety, and to comply with environmental regulations. These electrotechnologies and other high-efficiency electric technologies are described in the *Metal Finishing* guide (EPRI TR-106676-V6), which is available from the EPRI Distribution Center. To order this publication or other guides in this series, call the Center at (510) 934-4212.

## Electrotechnologies for Metal Finishing

	<b>Aqueous &amp; Semi-Aqueous Cleaning</b>	<b>Ultrasonic Cleaning</b>	<b>Electric Infrared Drying &amp; Curing</b>	<b>Ultraviolet Curing</b>
<b>Description</b>	Aqueous systems use heated mixtures of alkaline cleaners to lift and remove soils; semi-aqueous systems use dilute solvent solution to clean heavier soils.	Uses electrically generated high-frequency sound waves to create microscopic bubbles in aqueous or semi-aqueous solutions; explosion of the bubbles at the surface of the parts helps “scrub” parts clean.	Uses portable or stationary systems of quartz lamps and reflectors to direct short- and/or medium-wave radiation at a cleaned or coated part; heat is absorbed by the part, quickly drying it from the inside out and eliminating the problem of blistered coatings.	Ultraviolet radiation lamps trigger a chemical reaction that transforms radiation-curable coatings from liquid to solid.
<b>Metal Finishing Need</b>	Metal finishers need alternatives to solvent-based cleaning systems that can remove surface contaminants just as effectively and also eliminate environmental concerns.	Metal finishers need alternatives to solvent-based cleaning systems that can remove surface contaminants just as effectively and also eliminate environmental concerns.	Easy-to-operate technologies are needed for quick drying of all types of parts and for curing all paints and coatings, including the newer high-solids, waterborne, and powder coatings.	Solvent-based coatings emit hazardous volatile organic compounds during the drying process; alternative, solvent-free drying methods are needed.
<b>Application</b>	Metal parts are cleaned prior to plating or coating to eliminate surface contaminants that might interfere with later processes; aqueous and semi-aqueous cleaning can replace conventional solvent-based systems.	Metal parts are cleaned prior to plating or coating to eliminate surface contaminants that might interfere with later processes; ultrasonic cleaning can boost the effectiveness of aqueous and semi-aqueous solutions.	Used in drying parts and/or curing coatings; lamps are modular—spot heaters or panels can be arm-mounted for portability—or a group of lamps can be configured as a stationary oven.	Following coating, metal parts are exposed to ultraviolet light on a conveyor-driven process line for nearly instantaneous, emission-free curing.
<b>Benefits</b>	These cleaning solutions are less expensive than solvents, and they provide superior cleaning for a variety of organic and inorganic contaminants.	Reduces or eliminates solvent-related hazardous wastewater; cleans more quickly and effectively than mechanical agitation or spray washing.	Provides consistently high-quality results in 50–80% less time than convective ovens; requires no preheating; reduces requirements for ventilation and floor space.	Eliminates hazardous emissions, increases productivity through faster drying, requires minimal floor space, and provides a high-quality finish.
<b>Cost</b>	A complete cleaning and drying system costs \$10,000–\$710,000; the electrical requirement varies from 11–159 kW. Wastewater treatment is an additional cost.	A small, single-tank system costs \$3000–\$8000, a multistage system costs \$35,000–\$80,000; electrical requirements range from 1–48 kW, respectively.	A small spot or panel heater costs \$1000–\$2500; a custom-designed oven, \$10,000–\$250,000.	A typical small system costs \$1000–\$5500 and consumes 120–600 watts per inch; a fully automatic conveyor system costs \$8000–\$60,000 and consumes 200–800 watts per inch.

## Electrotechnologies for Metal Finishing

	<b>Outdoor Lighting</b>	<b>Ion Exchange</b>	<b>Electrolysis</b>	<b>Membrane Filtration</b>	<b>Vacuum Evaporation</b>
<b>Description</b>	Six types of lighting technologies are available. Each offers different characteristics in wattage, brightness, light tone, efficiency, and life span; they can be combined to meet site-specific needs.	Uses chemically treated resins in rinse water or acid baths to exchange metal and chemical ions for hydrogen or sodium ions, thereby decontaminating the solution for recycling.	Strips plating and rinse water of dissolved metal ions by passing an electric current through the wastewater, causing the ions to deposit on cathodes as a solid metal.	Electric pumps force wastewater through a permeable barrier that filters contaminants: microfiltration captures particles over 1000 angstroms; ultrafiltration, over 10 angstroms; and reverse osmosis, over 5 angstroms.	A closed-loop system in which process wastewater is vaporized under pressure at relatively low temperatures; as the water is driven off, dissolved salts concentrate in the effluent and then can be recycled in the process tank.
<b>Metal Finishing Need</b>	Lighting improves the visibility and attractiveness of a facility, reduces the potential for crime, and increases employee safety.	Metal finishers need to recover metals and chemicals from wastewater prior to discharge to reduce contamination, disposal costs, and, potentially, to recover costly materials for reuse or sale.	Metal finishers need to recover metals and chemicals from wastewater prior to discharge to reduce contamination, disposal costs, and, potentially, to recover costly materials for reuse or sale.	Metal finishers need to recover metals and chemicals from wastewater prior to discharge to reduce contamination, disposal costs, and, potentially, to recover costly materials for reuse or sale.	Metal finishers need to recover metals and chemicals from wastewater prior to discharge to reduce contamination, disposal costs, and, potentially, to recover costly materials for reuse or sale.
<b>Application</b>	Signage on or near the facility; general lighting in parking lots, walkways, delivery areas; facade and landscape lighting.	Separates metal salts and chemicals from dilute rinse water and regenerates acid baths; the metal-rich regenerant product can be further treated to recover the metal for reuse or sale.	Electrolysis is efficient at both high and low metal concentrations—for treatment of primary rinse baths, wastewater before ion exchange, and the effluent produced by ion exchange regeneration.	Microfiltration is used to regenerate both cleaning and process baths; reverse osmosis is primarily used to separate metal and chemicals from rinse baths; ultrafiltration can supplement both processes, as a step after microfiltration or prior to reverse osmosis.	Vacuum evaporation is used especially to recover temperature-sensitive plating baths and solutions with volatile components, although it is applicable to many metals, acids, and alkalies.

	<b>Outdoor Lighting</b>	<b>Ion Exchange</b>	<b>Electrolysis</b>	<b>Membrane Filtration</b>	<b>Vacuum Evaporation</b>
<b>Benefits</b>	Increased public perception of quality, goodwill, and success from general signage and facade lighting; reduced accidents, injuries, and crime from area lighting.	Effective at extracting virtually all of a given metal from a dilute waste stream; produces effluent suitable for discharge; relatively low capital and operating costs.	Recovers heavy metals in a reusable form, reduces the volume of toxic hazardous waste, improves rinse quality and life, and reduces overall water use.	Reduces the volume of hazardous waste, improves rinse quality and life, and reduces overall water use.	Allows recycling of all rinse water, produces no fumes or odors, minimizes the volume of sludge or concentrate requiring disposal, and nearly completely eliminates water discharge from a facility.
<b>Cost</b>	Systems are custom-designed to meet a facility's needs and budget.	A fully automated system processing 14,000 gallons per day costs \$35,000 to purchase and \$3500 per year to operate, if treating a 150 ppm waste stream.	Standard systems of cathodes in sizes 10–100 sq ft cost \$15,000–\$60,000 and consume 0.2–10.0 kWh/lb of recovered metal.	For systems processing 0.1–10.0 gallons per minute, respective purchase costs are \$5000–\$100,000 for microfiltration and ultrafiltration, and \$10,000–\$130,000 for reverse osmosis.	Units ranging in capacity from 0.01–1.0 gallon per minute require 1.5–20.0 kW, respectively, and cost \$7000–\$154,000; the payback period is typically 3 months to 1 year.

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# 1

## INTRODUCTION TO THE METAL FINISHING INDUSTRY

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Virtually every manufactured or fabricated product made of or containing metal features some type of metal finishing. The metal finishing industry is one of the most competitive and capital-intensive industries in the United States. It is also one of the most chemical-intensive and heavily regulated industries in the country. Its sales depend on the economic and market forces that shape the demand for individual manufactured products. The industry is highly fragmented, dominated by small facilities typically located near manufacturing customer bases. A gradual consolidation of the industry is expected—a result of competitive pressure from offshore manufacturing as well as U.S. environmental regulations.

### **Business Overview**

The business challenges facing metal finishers include intensified competition, increased operating costs, and environmental compliance. Environmental policy, especially, exerts tremendous influence, creating ripples that have a significant effect on the operating costs and competitive dynamics of the industry. This policy has undoubtedly already reduced the total number of metal finishing establishments because of its tacit requirement for access to capital. Shops with limited resources—those that cannot make necessary compliance-related upgrades—are forced to fold. Environmental policies are also contributing to changes in business strategy (e.g., process specialization). Overall, it is likely that the adoption of new technologies within the metal finishing industry over the next several years will be largely driven by regulations enacted to protect the environment.

Metal finishing establishments can be divided into two groups: independent “job shops” that perform metal finishing as their primary business, and “captive” operations found within companies that manufacture products requiring metal finishing.

Job shops typically perform a few specialized operations and are classified as either SIC 3471 (Electroplating, Plating, Polishing, Anodizing, and Coloring) or SIC 3479 (Coating, Engraving, and Allied Services Not Elsewhere Classified). According to the U.S. Department of Commerce (DOC), there were 5252 establishments classified in these two SIC codes in 1993 (see Table 1). The total value of shipments for both types of metal

finishing job shops was approximately \$11 billion that year and was divided almost equally between plating and coating services. Over the past 10 years, however, the number of electroplating facilities has decreased 4.3%, while the number of coating facilities has increased 20%.

Metal finishing processes are integral parts of aerospace, electronic, defense, automotive, furniture, domestic appliance, and many other industries. As a result, captive metal finishing operations can be found in a significant number of the establishments classified in SICs 34–39 (the metals industry). As opposed to job shops, captive metal finishing facilities typically perform a variety of manufacturing tasks in addition to metal finishing operations. As a result, captive metal finishing operations are found in over one-fourth of the manufacturing establishments classified within SICs 34–39. The total value of shipments for the metals industry was over \$1.28 trillion in 1993. Although this figure takes into account all process operations, not just metal finishing activities, it illustrates the importance of the metals industry to the U.S. economy.

Because there are both job shops and captive operations, it is difficult to estimate accurately the number of metal finishing establishments in the United States. A 1993 Office of Technology Assessment report (*Environment and Competitiveness in the Metal Finishing Industry*) states that captive operations represent 85–90% of facilities performing metal finishing operations. The report also notes that estimates of the number of facilities that use captive metal finishing vary from 20,000 to 80,000. Data published in *Metal Finishing Industry Market Survey, 1993–1994*, a market survey performed by the National Association of Metal Finishers (NAMF), show an estimated 37,000 metal finishing shops in the United States. This NAMF figure represents approximately 25% of the nearly 148,000 establishments classified as SICs 34–39 in 1993.

**Table 1**  
**Profile of the Metal Manufacturing and Finishing Industry (1993)**

Segment	No. of Establishments	No. of Employees	Value of Shipments (\$ billions)
Fabricated Metal Products (SIC 34)	36,416	1,371,072	175.1
Electroplating (SIC 3471)	3,282	67,623	5.4
Coating and Engraving (SIC 3479)	1,970	44,887	5.6
Industrial Machinery and Equipment (SIC 35)	54,436	1,749,735	278.1
Electronic and Other Electric Equipment (SIC 36)	17,073	1,424,351	233.6
Transportation Equipment (SIC 37)	11,420	1,601,554	414.7
Instruments and Related Products (SIC 38)	11,419	878,379	137.4
Miscellaneous Manufacturing Industries (SIC 39)	17,183	375,501	42.4
<b>TOTAL (SIC 34-39)</b>	<b>147,947</b>	<b>7,400,592</b>	<b>1,281.3</b>

Source: U.S. Department of Commerce, Bureau of the Census, 1993 *Economic Census*.



The seemingly high proportion of captive operations obfuscates the fact that an increasing number of manufacturing firms are choosing to outsource their metal finishing to job shops. This trend has several explanations. Metal finishing is typically the last operation before product sale or final assembly. It can require capital-intensive operations but may have a minor impact on the overall market value of the product. Metal finishing is also chemical-intensive and generates waste streams that are expensive to treat; as a result, the industry is facing more stringent environmental regulations. This fact may be one reason for the growth in the number of job shops performing painting rather than plating operations.

Although environmental compliance issues and costs are the suspected key drivers for outsourcing, larger manufacturing firms may choose outsourcing in conjunction with other manufacturing and production changes. With the advent of cellular manufacturing, flexible manufacturing systems, and the reexamination of cost structures, large manufacturers are streamlining their operations. Some are finding it unacceptable to have finishing capacity that is utilized only 20–30% of the time taking up valuable floor space at a potentially substantial overhead cost.

Overall, the metal finishing industry is dominated by small businesses. Within the job-shop segment (SICs 3471 and 3479), over 65% of establishments employ fewer than 20 people and 90% employ fewer than 50 people (see Table 2). According to NAMF, the average metal finishing shop employs between 15 and 25 people and has a sales volume of approximately \$1.1 million, with net profits of 5% of sales. Within the captive operations segment (SICs 34–39), 84% of all establishments employ fewer than 50 people. Again, this figure takes into account all process operations, not just metal finishing activities.

**Table 2**  
**Distribution of Metal Finishing Operations by Size (1993)**

Segment	Number of Employees						
	Small (0-49)		Medium (50-100)		Large (100+)		
	No.	% of Total	No.	% of Total	No.	% of Total	
Fabricated Metal Products (SIC 34)	30,141	83	3,247	9	3,028	8	36,416
Electroplating (SIC 3471)	2,981		207		94		3,282
Coating Engraving (SIC 3479)	1,761		137		72		1,970
Industrial Machinery and Equipment (SIC 35)	48,193	89	3,100	5	3,143	6	54,436
Electronic and Other Electrical Equipment (SIC 36)	12,351	72	1,814	11	2,908	17	17,073
Transportation Equipment (SIC 37)	8,735	76	865	8	1,820	16	11,420
Instruments and Related Products (SIC 38)	8,894	78	934	8	1,591	14	11,419
Miscellaneous Manufacturing Industries (SIC 39)	15,631	91	812	5	740	4	17,183
TOTAL (SIC 34-39)	123,945	84	10,772	7	13,230	9	147,947

Source: U.S. Department of Commerce, Bureau of the Census, *County Business Pattern 1993-United States*, (CBP-9-1), 1996

Metal finishing shops are located across the country but are concentrated most heavily in manufacturing regions; that is, near their customers. According to NAMF, the majority of metal finishing shops are located in the Midwest, West, and Northeast. Recent estimates have shown some geographic dispersion; these estimates suggest that changes have occurred as a result of the growth of manufacturing operations in certain areas (e.g., the Carolinas), and in the establishment of more stringent environmental regulations in others (e.g., the Great Lakes). However, traditional industrial regions, such as the Great Lakes and Mid-Atlantic states, still host large numbers of shops.

In terms of individual states, DOC data for SICs 34–39 show that California has the largest number of metal finishing facilities—both job shops and captive operations—with over 14% of the industry (20,859 establishments). Other top metal manufacturing and finishing states include Texas (8898 facilities), Ohio (8718 facilities), Michigan (8699 facilities), Illinois (8613 facilities), and New York (8596 facilities), each representing about 6% of the industry (see Figure 1). Rounding out the top 10 states are Pennsylvania (6942), Florida (6101), New Jersey (5131), and Massachusetts (4636).

## The Metal Finishing Process

Metal finishing involves a series of processes that give the surfaces of manufactured metal parts desirable physical, chemical, and/or aesthetic qualities. According to the U.S. Environmental Protection Agency (EPA), there are 46 different metal finishing processes; that is, processes featuring different technologies, operational steps, inputs, and outputs. It is common for metal finishing facilities to combine several of these processes into one overall finishing process (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 adds to the complexity of nomenclature. As a result, to simplify, metal finishing is typically divided into four major process “families.”

States	Facilities
CA	20,859
TX	8,898
OH	8,718
MI	8,699
IL	8,613
NY	8,596
PA	6,942
FL	6,101
NJ	5,131
MA	4,636



Figure 1  
Top 10 States for Manufacturing and Finishing (1993)

- 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
- 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 section discusses the general steps involved in the inorganic (plating) and organic (painting or coating) finishing of metal products (see Figure 2). These steps include

fabrication, cleaning, and surface preparation; finishing (with either inorganic or organic materials); and removal. Some products are also dried or cured following organic finishing.

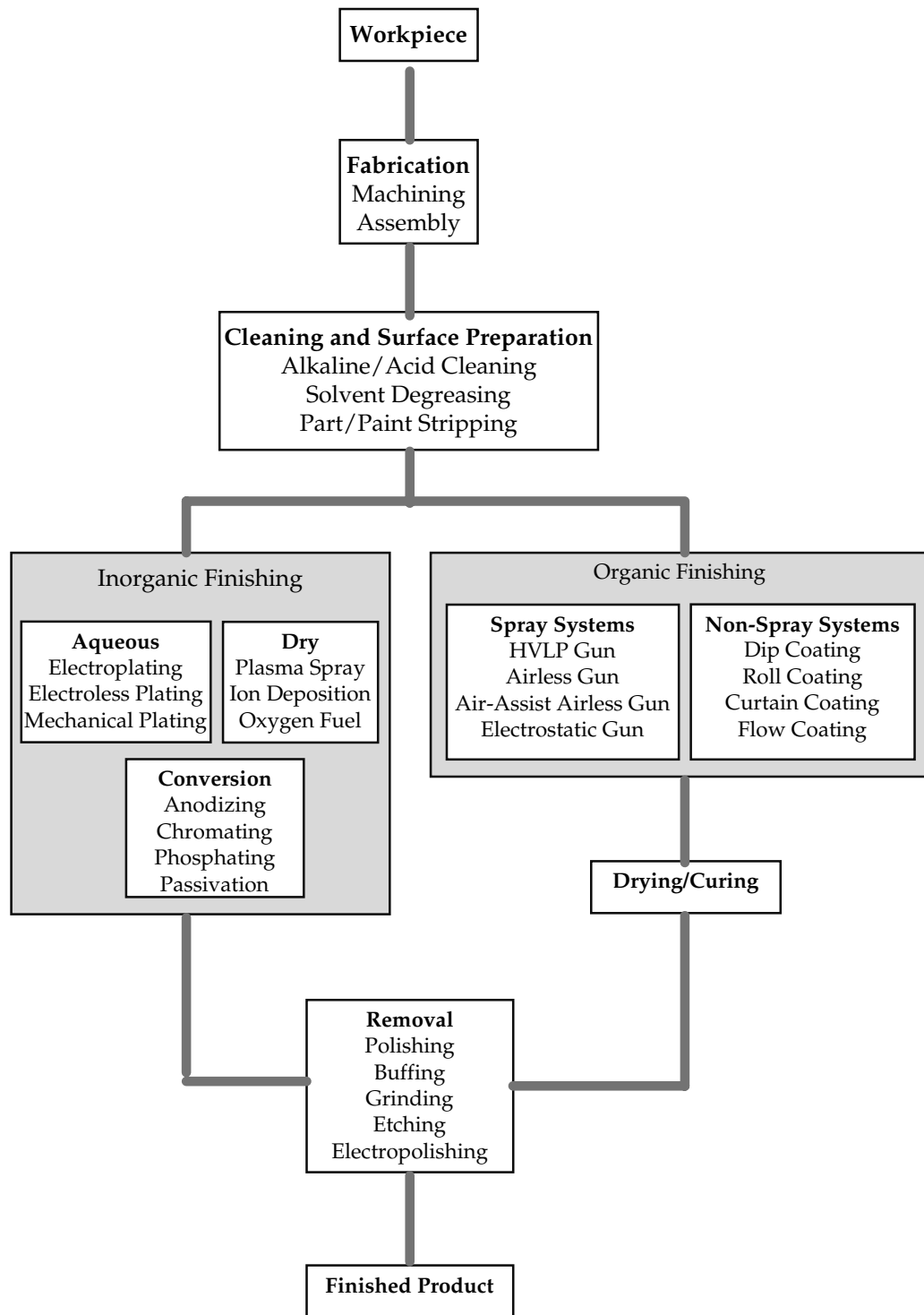


Figure 2  
The Metal Finishing Process

## **Fabrication**

Metal fabrication involves a variety of machining operations and/or assembly of metal components prior to cleaning, prepping, and finishing.

**Machining.** The machining operations typically used in metal finishing include stamping, turning, milling, grinding, drilling, boring, tapping, and sawing. In machining processes, cutting tools travel along the surface of a workpiece, shearing away metal. Most of the electricity consumed in cutting is transformed into heat, the major portion of which is carried away by the metal chips; the remainder is divided between the tool and the workpiece. Machining operations therefore incorporate the use of natural and synthetic oils for cooling and lubrication.

**Assembly.** Many metal products manufacturers assemble final products or subassemblies prior to finishing. Welding, joining, and fastening are common methods of assembly.

**Cleaning and Surface Preparation.** Cleaning and surface preparation operations are integral to a number of metal finishing processes. In order to ensure a good bond with the finishing material, the surface of the workpiece must be properly cleaned and prepared. Cleaning involves the removal of oil, grease, and dirt from the surface of the workpiece using water (with or without detergent) or other dispersing agents. Types of cleaning include

- **Alkaline Cleaning.** Alkaline cleaning 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 a 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. 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.

- **Part/Paint Stripping.** Paint stripping is the process of removing an organic coating from a workpiece, usually with a solvent, caustic, acid, or molten salt solution.

## **Inorganic Finishing**

Inorganic finishing is common among most industries engaged in forming and finishing metal products. It involves altering the surface properties of a workpiece in order to increase corrosion- and/or abrasion-resistance, change its appearance, or in some way enhance the utility of the product. There are two types of inorganic finishing processes—aqueous-based and dry-based processes.

**Aqueous.** Aqueous-based finishing involves placing a workpiece into a concentrated chemical solution to clean, activate, plate, and/or seal it. The workpiece is then removed from the solution and transferred to another solution—usually water—to remove excess chemicals. The workpiece goes through a series of concentrated chemical baths designed to produce the desired end product. The basic processes include electroplating, electroless plating, and mechanical (or contact) plating.

**Dry.** Dry-based finishing processes involve plating metals onto a workpiece without the use of process solutions or plating baths. During the plating process, many of the dry plating methods change the coating 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.

## **Conversion**

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.

**Anodizing.** 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 an insoluble oxide that provides wear resistance and/or prepares the aluminum to receive decorative coatings.

**Chromating.** Chromating is a conversion process for nonferrous metals such as aluminum, zinc, copper, and cadmium. It provides a decorative surface, corrosion resistance, and/or allows paint to adhere. Chromating involves a controlled corrosion of the metal surface and penetration by a chromium-metal gel.

**Phosphating.** Phosphating is the treatment of iron, steel, and other metals for corrosion protection and to promote the adhesion of paint. It involves a controlled corrosion of the metal surface followed by the deposition of a mineral coating (typically an iron or zinc phosphate) that becomes tightly bonded to the surface of the metal part.

**Passivation.** Passivation is the immersion of stainless steel parts in a nitric acid-based solution to remove metal contaminants and achieve a corrosion-resistant oxide surface. It is common for metal parts that have undergone handling and processing operations in which iron or steel particles may have become embedded in the substrate.

## **Organic Finishing**

Organic finishing (organic meaning that the finish includes carbon compounds) involves the deposition of a pigmented coating on the surface of a metal workpiece to alter the appearance or in some way enhance the utility of the product. The majority of metal finishers perform organic finishing of metals for both protective and decorative purposes. There are two types of organic finishing methods, spray systems and non-spray systems; both require drying or curing.

**Spray Systems.** Spray systems, such as high-volume, low-pressure (HVLP) airless, air-assisted, and electrostatic guns have significantly higher transfer efficiencies than conventional spray methods and can be used on a variety of metal parts and components. These systems make efficient use of coatings and labor and help to reduce emissions of volatile organic compounds (VOCs).

**Non-Spray Systems.** Non-spray systems, such as dip coating, roll coating, curtain coating, flow coating, and tumbling, have high transfer efficiencies; however, they are rarely appropriate for parts that traditionally have been sprayed. Because these methods tend to use more coating material and are relatively labor-intensive, they are used less often than others.

Once a coated metal part leaves the finishing area, it must be dried or cured. Conventional drying involves allowing materials to air dry or passing them through a natural gas-fired convection oven. Alternatives to conventional drying include infrared drying and ultraviolet curing. These alternatives significantly speed the drying/curing process and permit the use of VOC-reduced or VOC-free coatings.

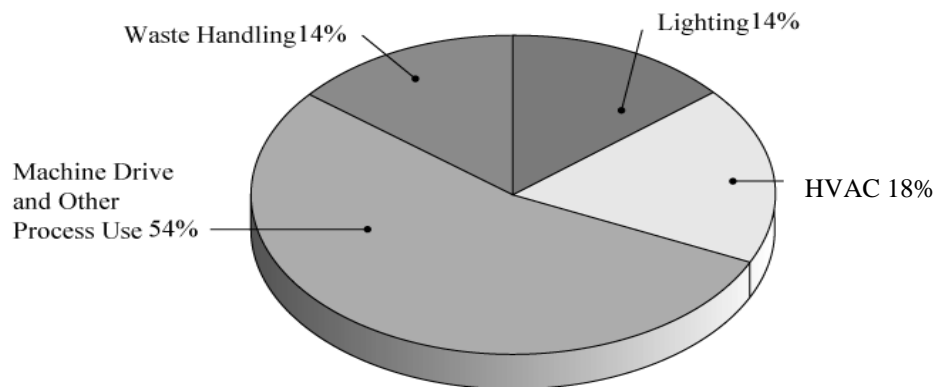
## Removal

Removal processes remove metal from the substrate through physical action or chemical reaction. Polishing, buffing, and grinding are examples of physical processes used to create a smooth, clean finish. Chemical processes include etching, which selectively removes metals from targeted areas on a workpiece, and electropolishing, which uses an electric current and achieves a smooth, highly reflective finish.

## Energy Use

As reported by the U.S. Department of Energy, in 1991 the metal manufacturing and finishing industry (SICs 34–39, including both job shops and captive operations) consumed a total of 1198 trillion Btu. Of this total energy use, 44% was natural gas and 41% (or 144 billion kWh) was electricity; fuel oil, coal, and other sources account for the remaining 15%. SIC 36 (Electronic and Other Electrical Equipment and Components, except Computer Equipment) was the most electric-intensive industry segment, with 51% of total energy coming from electricity. SIC 34 (Fabricated Metal Products, except Machinery and Transportation) was the least electric-intensive industry segment, with 33% of total energy coming from electricity.

Of the approximately 144 billion kWh of electricity consumed that year, 54% was consumed in process applications—to drive machinery, process heating, and process cooling equipment (see Figure 3). Non-process electricity use was consumed primarily by heating, ventilation, and air conditioning (HVAC) operations (18%) and by lighting (14%). The remaining 14% was consumed in other applications such as wastewater treatment, recovery of metals and solutions, and sludge management.



Source: U.S. Department of Energy/Energy Information Administration, *Manufacturing Consumption of Energy, 1991*, DOE/EIA-0512 (91).

Figure 3  
Electricity Use in the Metal Manufacturing and Finishing Industry



# 2

## BUSINESS CHALLENGES AND NEEDS

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The primary challenges facing metal finishers in both job shops and captive operations are competition from other domestic and international metal finishing shops and operations, high operating costs, and increasingly stringent environmental regulations. Combined, these factors result in a highly price-competitive industry. A metal finishing shop that incorporates a new, capital-intensive pollution-prevention technology may be forced to raise its prices to cover costs, potentially pricing itself out of a contract or out of business entirely. To succeed despite these challenges, metal finishers are striving to differentiate themselves by adding new plating or coating processes and chemistries while simultaneously reducing operating costs and complying with environmental regulations. These goals are closely related and can be achieved through a range of process changes and investments in new technology.

### Competition

Both domestic and international competition are on the rise. The extent of the competition, however, is determined by whether facilities perform “low value-added” or “high value-added” metal finishing. Low value-added finishing firms serve a variety of markets and finish relatively high volumes of simple parts that do not have special performance or other requirements. Product examples include materials that have simple geometries and are not produced to high specifications (e.g., domestic appliances, furniture, larger automotive parts). These firms compete almost exclusively on price, striving to be the lowest-cost provider. Although no statistics are available, industry sources believe that over half of the metal finishing establishments in the United States are low value-added firms. Low value-added firms are often capital-poor due to severe price competition; they use older processes because they cannot undertake the risk of investing in technical upgrades. They are also highly susceptible to international competition. As more U.S. companies fabricate and assemble products outside of the country—in order to take advantage of cheaper labor—some of these metal finishers will also shift to overseas locations. Relocating overseas to stay close to their manufacturer customers will allow metal finishers to reduce labor costs and minimize transportation costs.

High value-added 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 materials with complex geometries that must meet exacting specifications, such as defense and aerospace materials, medical instruments, and electronic components. These firms face less price competition because their work is specialized; they have closer relationships with their customers, and there is less likelihood of international competition. It is estimated that fewer than half of all metal finishing establishments are of this type.

## **Need**

### ***Reduce Operating Costs***

As in many other industries, low price, high quality, and quick delivery are three important goals for metal finishing job shops and captive operations. Price is the preeminent concern; in fact, metal finishing may be one of the most price-competitive industries in existence. Certainly the current marketplace encourages this competition: Many shops provide metal finishing, and the finishing processes themselves are relatively undifferentiated. Most of the facilities producing low value-added products use similar processes; high value-added facilities may use different processes to produce similar products. As a result, most manufacturers (both low and high value-added) can aggressively pursue the best price. The differentiation that does exist in metal finishing in some circumstances can be overcome through relatively small investments that would expand production to different plating processes and chemistries.

Complicating the desire for low operating costs is an industry trend toward increased worker skill and development. Experienced workers are highly valued for the knowledge they accumulate over time. The industry has traditionally relied on this experienced worker “know-how”; now shops are beginning to institute formal worker training as a supplement. Although taking time out for such training will increase labor costs in most facilities, more knowledgeable workers can become a foundation for improvements in metal finishing processes and waste reduction practices, thereby increasing productivity and reducing operating costs in the long run.

### ***Technology Solutions***

Operating costs can be reduced by using energy-efficient motors, adjustable speed drives (ASDs), and energy-efficient lighting technologies. Heat recovery heat exchangers and heat pumps can also reduce a metal finisher’s operating costs by recovering waste heat. In addition, wastewater treatment technologies—such as ion exchange, electrolysis, and membrane filtration—can help reduce waste disposal costs. Vacuum evaporation technology reduces the volume of sludge requiring disposal, thereby minimizing disposal costs.

*See pages 3-3, 3-4, 3-5, 3-16, 3-17, 3-18, 3-20, 3-21*

## **Need**

### ***Increase Productivity and Flexibility***

As is true in all aspects of manufacturing, a metal finisher can compete more effectively by increasing shop productivity (the number of products finished in a certain period of time that meet quality-control standards), and/or by increasing flexibility (the ability to finish a greater variety of metal products in a greater number of ways). Increased productivity can allow a metal finisher to reduce a product's price by reducing the amount of labor needed to finish a certain number of metal products. Increased flexibility, represented through new services, can attract new customers and/or additional business from existing customers.

### ***Technology Solutions***

Infrared drying and ultraviolet curing technologies can improve productivity—by speeding up the finishing process and reducing the number of defects. They can enhance flexibility by expanding the range of coatings a shop can dry or cure. Retrofitting with energy-efficient indoor lighting not only results in reduced energy consumption for lighting, but often results in improved lighting levels for employees. Improved lighting has been demonstrated to enhance productivity by reducing headaches and eye strain.

*See pages 3-14, 3-15, 3-17, 3-18*

## **Environmental Regulations**

Companies that perform metal finishing operations historically have been subject to extensive environmental, safety, and health regulations. These regulations are a direct by-product of the hazardous nature of the work and the many chemicals involved in metal finishing processes. The metallic compounds used in organic solvents and the electroplating processes are the primary materials triggering environmentally related regulations. Indications from the EPA suggest that any changes in current environmental, safety, and health regulations will enforce even more stringent rulings regarding the use, handling, and disposal of metal finishing materials.

## **Need**

### ***Comply With Environmental Regulations***

Metal finishers are currently regulated by the Clean Air Act and the 1990 Clean Air Act Amendments, the Clean Water Act, the Resource Conservation and Recovery Act, and

Superfund. Metal finishers are also affected by Occupational Safety and Health Administration regulations.

### ***Clean Air Act Amendments (CAAA) of 1990***

Air pollution regulations are an area of primary concern for metal finishers. Increased environmental protection legislation, in the form of the CAAA, brought additional challenges to metal finishing shops in the 1990s. Since many of these regulations are just beginning to be implemented across the country, their impact on the metal finishing industry is not yet known. Under the CAAA, any metal finishing operation with processes emitting VOCs or hazardous air pollutants (HAPs) could be required to obtain an operating permit and/or comply with other regulatory requirements for those processes. The metal finishing industry uses significant quantities of solvents and solvent-based paints that evaporate as VOCs at room temperature. These VOCs combine with nitrous oxide (NO<sub>x</sub>) in the presence of sunlight to form ozone, a major component of smog. Until the CAAA, VOC emissions were left largely uncontrolled.

Ozone levels in many areas of the country exceed the standards set by the EPA. States can either adopt the federal rule or promulgate their own more stringent rules. In many states, counties, and cities, special VOC regulations exist that require shops to reduce the amount of VOCs released into the atmosphere. Given these regulations, shops in many areas of the country are facing the choice of adopting alternative reduced-solvent or solvent-free coatings, using special spray equipment to limit the amount of VOCs escaping into the atmosphere, or installing emissions control equipment. Shops in other areas, particularly areas that meet federal ozone standards, may not encounter such regulations unless they have the potential to emit more than 10 tons of VOCs per year, in which case they fall under the EPA regulation regardless of location.

The metal finishing processes most affected by the CAAA's VOC and HAP regulations are painting operations that use halogenated solvents, paint-stripping processes involving solvents, parts-cleaning operations using solvents, and electroplating operations that have the potential to release certain metallic compounds into the atmosphere. The CAAA also targets a variety of plating operations, particularly chrome plating. The "Chromium Electroplating and Anodizing National Emissions Standards for Hazardous Air Pollutants" regulation was issued by the EPA in November 1994. This regulation to control air emission of chromium affects over 5000 facilities nationwide. Decorative chromium electroplaters must have achieved compliance by January 25, 1996; hard chromium electroplaters and chromium anodizers must comply by January 25, 1997.

With regard to HAPs, facilities that emit more than 10 tons per year of any one HAP, or 25 tons per year of any combination of HAPs, are designated "major sources" and are subject to the heaviest regulations. Metal finishing substances on the HAPs list include approximately 50 materials commonly used in paints; compounds containing cadmium,

chromium, lead, and nickel; and most organic solvents commonly used for paint stripping and metal cleaning. Major sources and some other specifically designated sources are required to obtain an emissions permit under Title V. The Title V permit includes emissions standards that require metal finishers to apply the Maximum Achievable Control Technology (MACT) to all new sources of HAPs at the facility; less rigorous standards apply to existing sources. Title V permits also include a number of monitoring and record-keeping requirements.

### **Clean Water Act (CWA)**

The primary objectives of the CWA are to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. Pollutants regulated under the CWA include "priority" pollutants, which are various toxic compounds; "conventional" pollutants, such as biological oxygen demand, total suspended solids, fats, oils, greases, fecal coliform, and pH; and "nonconventional" pollutants, which include all others not categorized.

To meet the requirements of the CWA, the EPA has developed technology-based standards for metal manufacturing and finishing businesses that discharge to a publicly owned treatment works (POTW). These "categorical" pretreatment standards are compiled in guidelines applicable on a nationwide basis; similar effluent guidelines already exist for the electroplating and metal finishing industries. In addition, "local limits" (which tend to be more stringent than EPA requirements) are developed by individual POTWs to assist them in achieving the effluent limitations established by their National Pollutant Discharge Elimination System (NPDES) permits. The vast majority of small metal finishing facilities discharge to POTWs. Failure to meet POTW requirements can result in sewer surcharges, fines, and even civil or criminal charges, depending on the severity of the violation.

The new Metal Products and Machinery (MP&M) category of the CWA includes a variety of businesses not covered by the EPA's metal finishing and electroplating guidelines. The MP&M category will cover all industries that manufacture, rebuild, and maintain finished metal parts, products, or machines. The MP&M guidelines were proposed in 1995 and finalized in early 1996; Phase I covers seven industrial sectors and took effect in 1996. The seven affected manufacturing sectors are aerospace, aircraft, electronic equipment, hardware, mobile industrial equipment, ordnance, and stationary industrial equipment. Phase II, slated to take effect in 1999, will cover eight additional sectors: bus and truck, household equipment, instruments, motor vehicles, office machines, railroad, shipbuilding, and precious and non-precious metals.

The EPA has analyzed the role small businesses play in the MP&M industry and examined the expected impacts of the new guidelines. The analyses showed that the MP&M industry is largely composed of small businesses, a substantial number of which will be affected by the CWA regulation. The EPA estimates that 75% of the over 10,000

facilities in MP&M Phase I industries are small businesses, that 25% of these facilities have fewer than 10 employees, and that 50% have fewer than 80 employees. The EPA found that the CWA regulation will impose significant economic impacts, and that these will lead to facility closure more frequently among small businesses than among MP&M facilities in general. Specifically, the compliance cost burden is expected to be greater for small businesses than for MP&M facilities in general.

### **Resource Conservation and Recovery Act (RCRA)**

The sludge that is generated by metal finishing wastewater treatment systems can contain chrome, zinc, cadmium, and other heavy metals and is therefore listed as a hazardous waste by RCRA's Subtitle C. Certain other wastes are automatically defined as hazardous unless they are proven otherwise. Wastes in this category pertain to metal plating and include spent plating bath solutions, sludge from the bottom of plating baths, and spent stripping and cleaning bath solutions.

Most metal finishers are considered small-quantity generators (SQG) of hazardous waste—facilities that generate 200–2000 pounds of hazardous waste per month. If a facility is considered a SQG, it must obtain an identification number from the EPA and maintain a uniform manifest system when transporting sludge off-site for treatment or disposal. Most 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. As a result of the ban on land disposal of hazardous waste, getting rid of waste is now more expensive because it must be treated before deposit in a landfill. It is therefore likely that the majority of near-term regulation-related expenditures by metal finishers will relate to handling and disposing of sludge.

### **Superfund (The Emergency Planning and Community Right-to-Know Act, EPCRA)**

Under Superfund, or EPCRA, the EPA is moving toward “cradle-to-grave” responsibility for hazardous waste, making liability a key issue. The EPA has also expanded the list of chemicals on the Toxic Release Inventory (TRI); this could draw metal finishing operations into the TRI. Although most metal finishers do not release toxic wastes and/or handle hazardous materials in sufficient quantities to be affected by the TRI, the expansion could involve some facilities.

### **Occupational Safety and Health Administration (OSHA) Regulations**

In addition to the environmental regulations described above, metal finishers are affected by many OSHA regulations. These include requirements for emergency response planning, electrical safety, respiratory protection, flammable storage, noise protection, and a comprehensive hazardous materials program.

In addition to the CAAA regulations issued by the EPA to control the emission of chromium, OSHA intends to re-regulate worker exposure to hexavalent chromium within the metal finishing industry; a proposal is expected to be published in late 1997. The revision will significantly lower the employee permissible exposure level and will affect all facilities that engage in hard or decorative chrome plating, anodizing, and/or use chromate conversion coatings (products include household appliances and furnishings).

### **Technology Solutions**

Electric technologies for process heating, parts cleaning, and wastewater treatment and recovery can reduce generation of air pollutants (VOCs and HAPs), reduce the volume of wastewater and associated disposal costs, and reduce raw material costs by recovering metals and recycling chemical solutions.

*See pages 3-4, 3-5, 3-14, 3-15, 3-20, 3-21*





# 3

## TECHNOLOGY SOLUTIONS

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This section describes each of the technology solutions identified in the previous section. Each technology is summarized, linked by end-use application to a business need, and categorized as an “electrotechnology” or “efficiency technology.”

Electrotechnologies are selected new or alternative electric equipment options. In many metal finishing applications, the electrotechnologies can reduce operating costs, increase productivity or operating flexibility, and/or assist in pollution control.

Efficiency technologies offer opportunities to decrease energy use, but typically have no direct impact on production. Each technology is more completely described in Section 4, Electrotechnology Profiles. Vendors of these electrotechnologies, sources of information on efficiency technologies, and trade associations are listed in Section 5, Resources.

The technologies are grouped and discussed below according to their end use, beginning with “Machine Drive and Other Process Use,” the end use that represents the greatest percentage of total electricity use in the metal manufacturing and finishing industry. Table 3 summarizes these solutions.

**Table 3**  
**Technology Solutions to Metal Finishing Needs**

End Use	Solution Type	Technology Type	Business Needs		
			Reduce Operating Costs	Increase Productivity/Flexibility	Comply with Environmental Regulations
Machine Drive & Process	Efficiency Technology	Energy-Efficient Electric Motors	■	■	
Machine Drive & Process	Efficiency Technology	Adjustable Speed Drives	■	■	
Machine Drive & Process	Electrotechnology	Aqueous & Semi-Aqueous Cleaning			■
Machine Drive & Process	Electrotechnology	Ultrasonic Cleaning			■
Machine Drive & Process	Electrotechnology	Electric IR Drying & Curing		■	■
Machine Drive & Process	Electrotechnology	Ultraviolet Curing		■	■
HVAC	Efficiency Technology	Energy-Efficient Indoor Lighting	■		
HVAC	Efficiency Technology	Energy-Efficient Outdoor Lighting	■		
Lighting	Efficiency Technology	Energy-Efficient Indoor Lighting	■	■	
Lighting	Electrotechnology	Energy-Efficient Outdoor Lighting	■		
Waste Handling	Electrotechnology	Ion Exchange	■		■
Waste Handling	Electrotechnology	Electrolysis	■		■
Waste Handling	Electrotechnology	Membrane Filtration	■		■
Waste Handling	Electrotechnology	Vacuum Evaporation	■		■

### Machine Drive and Other Process Use

In this guidebook, machine drive and process uses are considered together as one end use because of their overlap within metal finishing operations. For example, in the process steps of heat treatment and drying or curing, electricity is used by the electrotechnology (such as induction heating or infrared curing) and/or by ancillary motors, fans, and blowers, often in combination with alternative forms of energy such as natural gas or oil.

## **Machine Drive**

Electric motors and drives account for over half of the process electricity use within the metal manufacturing and finishing industry (SICs 34–39), including both job shops and captive operation facilities. This electricity powers motor-driven equipment such as pumps, fans, and compressors for cooling, and other equipment such as conveyors and material handling equipment. The efficiency of motorized systems used in metal finishing can significantly influence the overall energy efficiency of a facility. Energy-efficient electric motors and ASDs offer metal finishers options to improve operations efficiency.

Power factor is one aspect of motor efficiency. Power factor refers to the relationship or “phase” of current and voltage in alternating-current electrical distribution systems; in other words, the relationship between actual power use and the power drawn from the distribution system. Theoretically, when power factor is 100%, current and voltage are in phase. In practice, however, a fully loaded motor typically has a power factor of about 80%, while a lightly loaded motor may have a power factor of 40% or less.

The effect of poor power factor is increased current flow, increased power loss, and motors that run less efficiently. This inefficiency results in higher electricity demand charges as well as any applicable power factor penalties (some utility rate schedules include these) and, therefore, higher electric bills. Power factor correction can reduce current flow and power loss and improve voltage regulation, thereby improving motor performance. All of these improvements can help a metal finisher reduce operating costs.

In a metal finishing facility, poor power factor is typically caused by underloaded or idling motors. To correct for this, motors that are continuously underloaded should be replaced with smaller motors, and motors that regularly idle for more than a few minutes should be equipped with controllers to stop them when they are not being used. A more general solution involves installing capacitors in a bank serving a group of equipment or at the utility point of delivery.

## **Efficiency Technology Solution** **Energy-Efficient Electric Motors**

Energy-efficient electric motors (also known as high- or premium-efficiency motors) are typically 2–6% more efficient than their standard counterparts. They cost 15–30% more than standard motors. Over a typical 10-year operating life, a motor can consume electricity valued at over 50 times the initial cost of the motor. As a result, energy-efficient motors are extremely cost-effective, with a simple payback on investment of less than 2 years, compared to the purchase of a standard efficiency motor. The payback is generally attractive unless electricity prices are very low or a motor is operated infrequently.

Energy-efficient motors offer more than just reduced electricity consumption. They are typically manufactured to closer tolerances, use better materials, and offer more robust construction than standard motors. This higher quality translates into improved reliability and reduced maintenance requirements.

### ***Efficiency Technology Solution Adjustable Speed Drives***

ASDs, also known as variable-speed drives, should also be considered for large motors, particularly on pumps and fans. These drives use solid-state electronics to vary the frequency and voltage of the electricity applied to a motor. By reducing the frequency below the nominal 60 hertz, ASDs can vary the speed of a motor. For many systems, especially those with centrifugal loads such as pumps and fans, reducing motor speed results in a significant reduction in electricity consumption. ASDs are most commonly applied to systems that have output requirements that change over time.

### ***Parts Cleaning***

Prior to plating or coating, parts must be cleaned 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. A number of solvents and processes exist for cleaning metal parts. 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 at the end of 1995, however, is forcing 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.

The solvent, aqueous, and semi-aqueous cleaning systems can be used with conventional parts-cleaning technologies including vapor degreasing, brush, wipe, rotary basket, immersion cleaning, and spray and power washing. A relatively new cleaning method, ultrasonic cleaning, is used in combination with aqueous or semi-aqueous cleaning systems. Specialized “precision cleaning” methods are used for cleaning intricate metal parts.

### ***Electrotechnology Solution***

#### ***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.

### ***Electrotechnology Solution***

#### ***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.

### **Precision Cleaning**

Precision cleaning is essential to the manufacture of intricate metal parts such as disk drives, computer peripherals, and printed circuit boards for aerospace, electronics, and automotive industries. It is also used for general industrial parts cleaning in metal finishing and machining applications. In most stages of the manufacture of metal parts, cleanliness is essential to the overall integrity of the product. Seven electrotechnologies

are currently available or in development for the cleaning of precision metal instruments.

- **Megasonic Cleaning.** Similar to ultrasonic cleaning, megasonic cleaning uses high-frequency acoustic energy to generate pressure waves in a liquid medium.
- **Carbon Dioxide Snow and Pellet Cleaning.** CO<sub>2</sub> snow allows liquid CO<sub>2</sub> to expand into a mixture of solid, liquid, and gaseous states simultaneously. CO<sub>2</sub> snow flakes loosen contaminants, which are then swept away by the gaseous CO<sub>2</sub>. CO<sub>2</sub> pellet cleaning propels hard pieces of frozen CO<sub>2</sub> with air or other gases at high velocities.
- **Plasma Cleaning.** Plasma cleaning uses radio frequency and microwave energy in a low-pressure vacuum chamber to remove very thin layers of organic contaminants.
- **Supercritical Fluid Cleaning.** Supercritical fluid cleaning dissolves contaminants and transfers them to a separator vessel where the fluid is subjected to temperature and pressure changes that cause the fluid to evaporate. The contaminants are then concentrated and drained.
- **UV/Ozone Cleaning.** UV/ozone cleaning combines UV radiation and chemical oxidation in a cleaning chamber to form highly reactive hydroxyl (OH-) radicals. These radicals react with organic compounds, breaking them down into carbon dioxide and water, thus removing contaminants.
- **Bioremediation.** Bioremediation uses microbes to degrade petroleum-based contaminants into fatty acids, carbon dioxide, and water.
- **Laser Ablation.** Laser ablation cleans by focusing laser energy onto a surface, which vaporizes any contaminants, or by vaporizing a thin liquid layer that, in turn, carries off the contaminants.

More information on precision cleaning technologies can be found in the *Electronic Components* guide (TR-106676-V11) of this series.

## Drying Cleaned Parts

Since moisture typically interferes with downstream manufacturing process steps, drying is an integral step in aqueous and semi-aqueous cleaning. Moisture tends to degrade labeling, coating, and plating processes and can damage intricate metal components, causing long-term quality problems. The drying process, however, must not re-contaminate the metal part with dust, dirt, or other particles.

There are several methods to reduce drying time, including

- using rinse agents that speed up drying,
- improving surfactant use to allow easier drying,

- improving the rinsing process to include ultrasonic and filtration systems that reduce water use,
- using multiple wash tanks to reduce soil loading in the rinse tank, and
- using recirculating hot air dryers.

A variety of nonelectric drying systems are available, including nitrogen-based drying, capillary drying, water-displacing oils, and nonozone-depleting solvent drying. The available electric drying systems are low- and high-velocity air drying, drying ovens, infrared heating lamps, centrifugal drying, and vacuum drying.

**Low-Velocity Drying.** Low-velocity drying systems (less than 10,000 feet per minute) are based on evaporation. Room air is filtered and heated above 200°F so it will absorb more moisture from metal parts. After circulating through the drying chamber, the moist air is vented. Advantages of low-velocity drying include low energy demand (although there is relatively high energy consumption per part compared to other electric drying methods), low noise levels, and small equipment footprint. Disadvantages include a longer drying time and a higher manual labor requirement for loading and unloading carriers.

**High-Velocity Drying.** High-velocity drying systems (10,000–35,000 feet per minute) use high-impact air jets to dry metal parts. The air is usually channeled through air knives or nozzles to increase moisture removal to 95–100%. Advantages of high-velocity drying are low energy consumption per part, shorter cycle times, and no manual labor. Disadvantages include high capital cost, high energy demand, higher noise levels, and larger space requirements.

**Drying Ovens.** Electric resistance drying ovens simply evaporate the moisture off the metal part by exposure to heated air. These ovens are common; however, they tend to cause spots and are not consistent in completely drying the metal part.

**Infrared Heating Lamps.** Electric infrared heat lamps produce heat via an infrared radiation emitter. The radiation is absorbed by the metal part, generating internal heat that evaporates moisture off its surface.

**Centrifugal Drying.** Electrically driven centrifugal dryers use centrifugal force to remove water, oils, rinses, and paints, while turbine fans simultaneously draw air across a metal part for added drying. This process is particularly effective for drying small plated parts. One disadvantage is that centrifugal systems can trap liquids in parts that have crevices.

**Vacuum Drying.** Vacuum drying permits the evaporation of liquids at a significantly lower temperature than normal. This process is particularly effective for drying parts with complex geometries.

## **Parts Stripping**

Parts stripping is another critical process performed prior to metal finishing. Stripping operations reprocess out-of-specification parts or remove old coatings. As an alternative to solvent-based stripping operations, electrically driven blasting systems employ a variety of manufactured and naturally occurring abrasives such as glass beads, agricultural products, plastic, and water to remove old coatings. Blasting operations are typically done after the cleaning stage to ensure that oil- and grease-type soils do not contaminate the abrasives. Typically, coarse abrasives are used in general cleaning, metallic abrasives in rough cleaning and shaping, and fine abrasives in cleaning and finishing. There are three primary types of blasting systems—dry, wet, and cold media.

**Dry Media Blasting.** Dry blasting blasts an abrasive (e.g., sand, agricultural products, plastics) onto a metal part using centrifugal force in the form of a rotating, bladed wheel, or using air pressure.

**Wet Media Blasting.** In wet blasting, an abrasive (e.g., sodium bicarbonate, sand, glass beads) is suspended in water to form a slurry. The abrasives used in this process are usually smaller than those used in dry blasting, allowing more control over metal or paint removal and surface modification.

**Cold Media Blasting.** Similar to precision cleaning with carbon dioxide snow or pellets, cold blasting combines carbon dioxide snow, pellets, or ice with air or other gases at high velocities to strip old coatings off metal parts.

## **Inorganic Finishing**

Once a metal part has been cleaned and prepared to specification, it is often coated to preserve its appearance; to add desirable aesthetic qualities; to provide a specific functional behavior (such as corrosion- or abrasion-resistance); or, in some instances, to prepare it for painting. Inorganic finishing, or plating, involves the deposition of a metallic, metalloid, ceramic, or other inorganic coating onto the surface of a metal substrate. Plating is performed through aqueous-based processes and dry processes.

**Aqueous-Based Processes.** There are three basic aqueous-based processes for depositing metal ions onto a substrate. Electroplating uses an electrical current; electroless plating uses chemical reactions; mechanical or contact plating uses direct contact with a metal-bearing solution. These processes can be used to deposit a variety of metals and combinations of metals onto metal substrates and are an extremely flexible and efficient method for giving metal substrates desirable properties. A key disadvantage is that aqueous-based processes also generate hazardous pollutants such as heavy metals, acid and alkaline wastewaters, and organic contaminants.



- **Electroplating.** 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 metal 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.
- **Electroless Plating.** 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.
- **Mechanical/Contact Plating.** Mechanical or “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.

**Dry Processes.** Several technologies plate metals onto parts without the use of process solutions or plating baths. Many of these dry processes are “vapor-phase” methods in which the coating material goes from a solid to a vapor-phase and then back to a solid phase when deposited on the part. The primary advantage of vapor-phase systems is the elimination of metal-bearing waste streams. Vapor-phase methods include plasma spray, ion beam-assisted deposition, ion plating, ion implantation, and high-velocity oxygen fuel spray.

- **Plasma Spray.** In plasma spraying, a powder coating material is heated to near or above its melting point. The plasma then propels the heated or molten particles toward the metal substrate. Almost any material that can be melted without decomposition can be used as a coating, including a number of metals and metal alloys.

- **Ion Beam-Assisted Deposition.** Ion beam-assisted deposition is a thin-film vacuum process that combines conventional vapor deposition with ion bombardment. The film can be any material that evaporates conventionally. During deposition, the film is continuously bombarded by ions from a low-energy ion source, altering the film structure on the substrate. The chemical composition and structural properties of the film can be altered by controlling the evaporation rate, the partial pressure of any reactive gas in the chamber during deposition, and the energy and current density of the ions that bombard the substrate during deposition.
- **Ion Plating.** In ion plating, the coating material is connected to an anode in a vacuum chamber. When heated, the coating material evaporates and moves along the electric field created by a glow discharge established near a cathode. The part to be coated is placed in contact with the cathode and is coated as the evaporated material condenses on the unheated surface. The vacuum chamber is backfilled with an inert gas to prevent oxidation of the surfaces being coated. Applications to date are limited to aluminum coatings and glass.
- **Ion Implantation.** Ion implantation accelerates ions to strike a metal part at energies high enough to bury them below the part's surface. Ion implantation can improve the wear, friction, and anticorrosion properties of metal surfaces. The number of ions implanted and the depth of implantation depend on the composition and structure of the metal substrate, the nature of the ions, the acceleration voltage, and the beam intensity. In general, the lower the voltage, the less the penetration depth. 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.
- **High-Velocity Oxygen Fuel Spray.** Metal composites can be applied as coatings on many conventional materials to improve strength, heat transfer, and electrical and magnetic characteristics. In this case, high-velocity oxygen is used during spray deposition to improve the characteristics of the metal composite coatings. The spray reduces the material particle size and allows greater control over the material microstructure.

## Organic Finishing

Organic finishing 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. Application of the coating can require a series of steps to provide the metal substrate with its final finish characteristics: a primer to promote adhesion and contribute to film thickness, an intermediate coat to provide compatibility between the

primer and the final coat, and one or more final topcoats to ensure specific performance and chemical properties. These coatings represent one of the most significant sources of environmental releases for a metal finishing facility.

Organic coatings come in powder and liquid forms and are made up of a variety of materials that serve different functions. Paint formulations typically include pigments to provide color, additives to provide desired coating properties, resins and binders to act as adhesives to the metal substrate and, in the case of liquid coatings, solvents or thinners to dissolve the resin and lower the viscosity of the coating. The choice of coating and application technology is based on the desired mix of physical properties (e.g., hardness, abrasion resistance, flexibility, and gloss) and chemical properties (e.g., resistance to corrosion, chemicals, water, high temperatures, and sunlight) required for the product.

**Coatings.** Regulation of VOCs and HAPs has driven the development of several alternatives to conventional solvent-based paints; these include high-solids, waterborne, powder, and ultralow/nonsolvent coatings.

- **High-Solids Coatings.** A transition from conventional coatings to high-solids coatings is often a metal finisher's first strategy to reduce VOC emissions. Unlike conventional coatings, which may be only 30% solids, high-solids coatings are up to 80% solids (with substantially reduced solvent content). New technology developments and delivery systems have overcome many of the performance and application problems that initially plagued high-solids coatings.
- **Waterborne Coatings.** As the name implies, waterborne coatings use water instead of organic solvents for the solvent component of a coating, although most waterborne coatings still release some VOCs or HAPs. As with high-solids paints, technology developments have extended the application of waterborne coatings into a number of high-performance areas. The primary advantage of their use is a reduction or even an elimination of VOC and HAP emissions. The primary disadvantages include slower drying times and potential for film defects.
- **Powder Coatings.** Powder coating is a dry coating process in which electrostatically charged particles of pigmented resin are sprayed onto a metal part. Compared to liquid coating systems, powder coatings provide far better environmental performance. No solvents are used in the mixing, application, or cleaning of powder systems, and the VOC content of resins is only 1%. In addition, paint waste is minimized through electrostatic delivery, and any overspray can be collected and recycled. These two advantages combined result in a minimum application efficiency rate of 90%. Powder system energy requirements also tend to be lower than those of solvent systems, due to exhaust air reuse and decreased exhaust flow during the drying/curing process.

- **Ultralow/Nonsolvent Coatings.** These coatings were developed for a number of specialty applications. One type, autophoretic coatings, are dip-based coatings for steel substrates and are suitable for large-volume coating operations with limited workpiece configurations (e.g., automotive parts, and appliance and furniture components). Electrocoatings are used to coat steel and aluminum substrates; their benefits include low VOC emissions, low hazardous waste generation, and low water pollution. Metal parts are moved through an electrocoating bath in which charged particles in the solution coat the metal parts. The solution contains a solvent (typically water), acidic or basic organic groups, inorganic solids, and an organic pigment to supply the desired color and properties. Polyurea coatings are 100% solids coatings that are impervious to water, suitable for any substrate, and can be formulated to achieve a variety of performance characteristics. These alternatives hold promise, but initial investment cost, space, and process control considerations may limit broad acceptance and implementation.

**Application Technologies.** To improve transfer efficiency and reduce paint waste, many metal finishers are switching not only to alternative 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. Most spray applications are conducted in specially ventilated spray booths that serve both environmental protection and OSHA functions.

Non-spray 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.

- **Dip Coating.** Dip coating is an inexpensive method of applying paint to metal parts, although it requires a rather large inventory of paint. In dipping, parts are immersed in a tank of paint; the excess paint is drained back into the tank as the parts are withdrawn. The rate of withdrawal from the tank determines the thickness of the film of coating.
- **Roll Coating.** Hand roller coating melds padding and brushing into one operation and is used primarily for decorative and maintenance coatings. Although little skill is required, the technique uses more paint than other coating methods because coatings are not consistent and there is no provision for recycling of waste paint. Automated roller coating is widely used and can be further divided into direct, reverse, and high-speed roller coating.
- **Curtain Coating.** Curtain coating is the reverse of dipping: a thin film of paint falls like a curtain from a slot in the bottom of a paint reservoir onto parts passing by below on a conveyor belt. Thick films can be built up inexpensively on large, flat parts using this technique.

- **Flow Coating.** In flow coating, the parts are placed on wire shelves in a closed chamber, and streams of paint are directed onto them. Excess paint drips into a tank below and is recycled.
- **Tumbling.** In this process, parts are tumbled in a metered amount of paint in a closed chamber. Tumbling is very cost-effective for painting large numbers of small parts or components.

Alternative, high-efficiency spray systems include high-volume, low-pressure (HVLP) spray guns, airless spray guns, air-assisted airless spray guns, electrostatic guns, and rotary bells and disks. These systems are widely used on a variety of metal parts and components.

- **High-Volume, Low-Pressure Spray Guns.** HVLP guns use an internal turbine to generate a high volume of low-pressure air to carry a coating to a metal part. Bounceback and overspray are minimal since the coating is atomized into particles at low air pressure and the particles are propelled at low velocity. The heated air used in these systems provides a second benefit: it decreases the coating viscosity without the use of solvents. HVLP guns may be the most flexible of the spray application 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 high-solids and waterborne coatings.
- **Airless Spray Guns.** Airless guns atomize paint under extremely high hydraulic pressures. By passing a high-fluid-pressure coating through a very small gun orifice, the paint is atomized and carried to the workpiece with minimal overspray. Airless guns are good alternatives for high-viscosity coatings and for painting large uncomplicated surfaces. The paint particles are typically too large for high-quality finishes, and minimal operator control makes the technique impractical for intricate work.
- **Air-Assisted Airless Spray Guns.** Air-assisted airless spray guns add compressed air, which atomizes the paint into finer droplets than possible with airless systems. The compressed air has the added benefit of reducing the necessary fluid pressures by over 50%. This system is limited to applications that do not need fine finishes.
- **Electrostatic Guns.** Electrostatic guns can be conventional, airless, or air-assisted airless, and can apply solvent-based, waterborne, and powder coatings. The substrate parts are electrically grounded, and electrostatically charged paint is directed by the air and attracted to the grounded parts. The electrical attraction between the charged paint particles and the workpiece substantially improves paint transfer efficiencies and reduces paint waste and cleanup labor. The technique is not well suited for very small parts or parts with recessed areas.

- **Rotary Bells and Disks.** Rotary bells and disks are another means of electrostatic application; in this case, the charged paint is centrifugally spun out by a rotating disk or bell to coat a predetermined field through which the parts pass on a conveyor. Rotary bells and disks are only feasible for high-volume production runs of parts with similar geometric makeups.

## **Process Heating**

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; these technologies can help a metal finishing facility increase productivity, reduce production costs, and/or enhance product quality, thereby reducing the number of defective pieces produced. Induction heating and indirect resistance heating are two electrotechnologies available for heat treating, heating, and preheating metal parts.

**Drying and Curing of Coatings.** Once a metal product leaves the finishing area, the coating must be dried or cured. This step is typically accomplished by allowing the materials to air dry, or by passing them through a natural gas-fired convection oven. Alternatives to conventional drying processes include IR drying and UV curing. These alternatives significantly speed the drying process while allowing the use of VOC-reduced or VOC-free coatings.

## ***Electrotechnology Solution*** ***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 non-solvent 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.

## **Electrotechnology Solution**

### **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.

**Heat Treating, Heating, and Preheating.** A variety of processes, including heat treating, heating, and preheating, are used to condition the surface of a metal prior to coating. Heat treating is typically accomplished by passing the metal through a gas-fired convection oven; alternatives include induction heating and indirect resistance heating. Induction heating uses a changing electrical field to induce electrical eddy currents in the workpiece. The eddy currents discharge energy, thus heating the workpiece. Indirect resistance heating passes a current through a resistance heating element. This element in turn transfers heat to the metal piece by radiation, convection, or conduction.

Induction and electric resistance heating offer several advantages over gas-fired furnaces, including fast startup and shutdown, quick heating, higher production rates, less scale and scrap loss, and a reduction in energy consumption. In addition, by using electricity instead of natural gas, these alternatives significantly reduce the emission of combustion by-products. Among the electric process heating methods, induction heating is currently preferred by the metals industry. In addition to preheating and heat treating, indirect resistance heating can be used in the finishing processes to bake vitreous enamel coatings onto metal substrates and to dry and cure organic coatings on a variety of metals.

### **Heating, Ventilation, and Air Conditioning**

HVAC accounts for nearly 20% of total electricity use within the metal finishing industry. Ventilation is critical in metal finishing facilities since the air can contain noxious and toxic compounds, such as volatile organics, strong alkalies and acids, hexavalent chromium, ammonia, and cyanide, during the cleaning and plating or coating processes. The ventilation must be sufficient to ensure that worker exposure remains within OSHA requirements and to minimize potential degradation of the facility. Balancing these large ventilation loads requires supplying large amounts of makeup air, which can burden the HVAC system. Depending on the climate, this

makeup air can provide a significant heating or cooling load. Also, because metal finishing processes are relatively energy-intensive—and produce heat—space cooling requirements around heated plating tanks, for example, can add considerable load to the HVAC system.

Because of heat from the metal finishing process, many facilities use chillers to provide year-round cooling. Electric chillers are efficient, reliable, and are commonly found in many industrial plants. Recent advances improve energy efficiency and accommodate environmentally friendly refrigerants.

In addition to generating large amounts of heat, the plating equipment requires effective ventilation to maintain an acceptable air quality level. The ventilation system should be engineered specifically to the physical configuration of each plating tank. Rim exhausts are the most frequently used exhaust method and are typically placed along both sides of the bath. Despite a common perception that pollutants emerge evenly from the bath surface, most emerge near the anodes and cathodes. In metal coating, approximately two-thirds of the pollutants are formed at the cathode rod in the center of the bath—the most difficult area to ventilate.

Higher bath temperatures strengthen the updrafts of pollutant-rich air above the bath and require stronger exhaust service to capture the emissions. As a basic rule of thumb, the exhaust flow required to achieve a certain degree of capture must be doubled for every 25–35°F rise in bath temperature.

Another design consideration is the height of the exhaust port above the bath surface. Since the air pollutant capture rate decreases as this distance increases, the exhaust port should be no more than 6 inches above the bath surface. Another rule of thumb is that the distance of the exhaust port from the bath surface should be less than 30% of the distance of the port from the cathode rod.

### ***Efficiency Technology Solution*** ***Heat Recovery Heat Exchangers***

The cost of conditioning the ventilation makeup air can be lowered by using a heat recovery heat exchanger, which transfers energy from the exhaust airstream to the makeup airstream. When high ventilation rates are combined with cold ambient conditions, heat recovery heat exchangers offer attractive opportunities for energy savings. Counterflow axial heat exchangers are inexpensive installations and can provide effective heat recovery; however, the properties of the exhaust air must be considered. Toxic and corrosive exhausts degrade ventilation surfaces and can be particularly harmful to heat exchanger materials, which are typically designed for thermal effectiveness rather than chemical stability. Also, the dew point of gases in the exhaust stream affects the feasibility of the heat recovery heat exchangers. If the



makeup airstream is sufficiently cooled, corrosive agents in the exhaust airstream may condense out and rapidly degrade the ventilation duct.

### **Efficiency Technology Solution**

#### **Heat Recovery Heat Pump**

Given the large amounts of heat generated by plating processes and the cooling needs of workers attending the equipment, a heat recovery heat pump provides an attractive opportunity for improved energy efficiency. Heat recovery heat pumps remove energy from warm areas, thus cooling them and (via vapor compression) transferring this energy to regions or process streams that need the heat. Many metal finishing processes require the addition of heat, and heat recovery heat pumps reject energy at temperatures of 120–180°F, useful for process and/or preheat functions. The cooling provided by heat recovery heat pumps increases the efficiency of the HVAC system.

As with heat recovery heat exchangers, the corrosiveness of the environment can dramatically shorten the life of heat exchanger surfaces in a heat pump system. Close attention to the environmental conditions and material selection is therefore essential.

### **Lighting**

Adequate lighting is critical to the timely completion of a properly shaped, treated, and finished product. Although lighting represents approximately 14% of a metal finishing shop's total electricity use, this energy use and cost is typically not a concern.

Due to the nature of the work, metal finishing shops require high lighting levels with good color rendition. The most common lighting system for metal finishing facilities is fluorescent tubes with magnetic ballasts. Fluorescent lamps are available in a variety of shapes and sizes. Some of the most commonly used are 4-foot-long tubes used in two-, three-, and four-tube fixtures. In larger facilities, 8-foot-long tubes are also used.

The second most common lighting source is incandescent light since these lamps are relatively inexpensive and easy to install. They are typically used in offices, hallways, and common areas but are not used for lighting the finishing areas. They can also be used in signs, displays, and for exit lighting. Incandescent light is, however, the least efficient lighting source available.

Another lighting system used in metal finishing shops, particularly the larger shops, is high-intensity discharge (HID) lamps. The HID family of lamps includes mercury vapor, metal halide, and high-pressure sodium lamps. All of these lamps are more energy-efficient than fluorescent lamps and have significantly longer lives.

### ***Efficiency Technology Solution***

#### ***Energy-Efficient Indoor Lighting***

The most efficient form of fluorescent lighting available today is the T-8 fluorescent lamp (tube or bulb) with an electronic ballast. Conversion from a magnetic (T-12, 40-watt) ballast to an electronic (T-8, 32-watt) ballast can be accomplished by either retrofitting the existing fixture or installing a new fixture designed for T-8 lamps, at a cost of roughly \$40 or \$100, respectively. Ceiling-mounted incandescent lamps can be successfully replaced with compact fluorescent lamps when the ceiling height is less than 12 feet, such as in hallways. Mercury vapor is the least efficient HID lamp; these lamps can be replaced with either metal halide or high-pressure sodium lamps with relatively short payback. (High-pressure sodium is more appropriate for outdoor lighting due to its orange hue.) Metal halide lights, which have a white hue, are still effective when mounted high up (e.g., in the rafters) to minimize their exposure to corrosive tank fumes, thereby reducing the cleaning and maintenance burden.

### ***Electrotechnology Solution***

#### ***Energy-Efficient Outdoor Lighting***

Outdoor lighting can also be a part of a metal finishing shop's energy bill. Existing applications range from incandescent lights on building signs to mercury vapor lights in the parking lot and driveway. These lighting systems normally represent only a small portion of the energy bill because they are only on for limited periods of time and because they seldom contribute to a facility's peak electrical demand. This means there may be relatively small savings potential from energy conservation projects. More significant benefits may accrue through increasing outdoor lighting to reduce the potential for crime, improve employee safety, and enhance the visibility of the facility exterior and grounds, and thus the perception of quality.

### ***Waste Handling***

In a typical metal finishing facility, approximately 14% of electricity use is for miscellaneous equipment handling wastewater treatment, metals and solution recovery, and sludge.

### ***Wastewater Treatment and Recovery***

Wastewater treatment and metal recovery is the primary environmental activity in the metal finishing industry. 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.

**Process Changes.** General waste minimization techniques and practices are still the most effective 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, these practices include bath maintenance, drag-out reduction, and zero water discharge.

- **Bath Maintenance.** Understanding the specific process chemistries and the sources and effects of contaminants is a key factor in developing preventive strategies to maintain bath life. Effective bath maintenance requires that the metal finisher know precisely the chemical sources, conditions, and circumstances leading to bath deterioration. Once these characteristics are identified, it is possible to improve process control and better tailor the use of treatment and recovery technologies.
- **Drag-Out Reduction.** As metal parts move from one plating or rinse bath to the next, they often contaminate the new bath with solution from the previous bath. This is known as “drag-out.” The amount of drag-out depends on the surface tension and viscosity of the solution, the physical shape and surface area of the metal object, and the amount of drainage time between steps. Process modifications, such as extended drain times or counterflow rinsing, can allow metal finishers to decrease material costs (e.g., solution costs) while increasing contaminant control and preserving bath life. Minimizing drag-out also reduces the toxicity of the rinse wastewater, reducing the amount of rinse water needed and the amount of heavy metal in treatment wastes, and therefore treatment and disposal costs.
- **Zero Water Discharge.** The concept of closed-loop discharge systems is gaining favor. While the idea of zero water discharge is valid, the non-water waste stream volumes (e.g., hazardous residuals, spent process solutions) will tend to increase since they are not diluted and discharged through wastewater. Such a system should be pursued only after determining that the regulatory and cost benefits of zero water discharge and water use reduction will outweigh the increased costs of hazardous waste disposal and shipping of spent process solutions.

A number of electric wastewater treatment and recovery technologies are commercially available or are being developed for the metal finishing industry.

**Treatment/Recovery Technologies.** 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. This process, however, produces a toxic sludge that must be properly disposed of as a hazardous waste.

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.

### ***Electrotechnology Solution*** ***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.

### ***Electrotechnology Solution*** ***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.

### ***Electrotechnology Solution*** ***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.

### ***Electrotechnology Solution*** ***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.

### ***Sludge Management***

The amount of sludge generated by the metal finishing industry has become an increasingly costly problem for business owners and operators, and an added stress on the environment because the sludge is typically hazardous. Regardless of the volume of hazardous sludge produced, metal finishers are concerned with both cost and liability in 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.** As the first step in sludge management, conditioning induces chemical or physical changes that enhance the ability of successive steps to remove water. 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 electrotechnologies 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 an electrotechnology ready for implementation in this process. Other electrotechnologies, 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. Electrotechnologies 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 5 years, sludge drying equipment has been one of the more frequently purchased pollution prevention and control systems. Electric resistance, electric 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.





# 4

## ELECTROTECHNOLOGY PROFILES

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This section provides profiles of the electrotechnologies identified in Sections 2 and 3. Each profile explains the technology, its advantages and disadvantages, commercial status, and costs. The profiles have been designed as stand-alone descriptions so they can be utilized separately from this guidebook. Turn to Section 5 for a list of equipment vendors that can provide further information as needed.

### **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—non-halogenated 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.

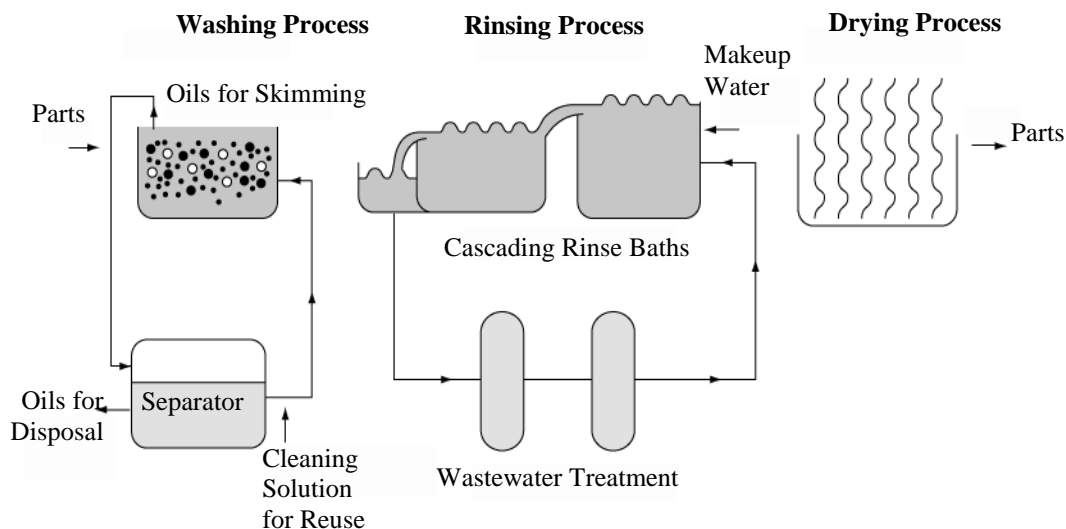
Aqueous solutions are customized to meet specific cleaning application requirements and are typically classified according to pH. Alkaline cleaners (pH>9) are the most commonly used cleaners in this family. They contain three elements: alkaline salts or builders, organic and inorganic additives, and 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.

#### ***System Description***

There are four steps to aqueous and semi-aqueous cleaning: washing, rinsing, drying, and wastewater treatment and disposal (see figure below). 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.



### Aqueous Cleaning Process

**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, infrared (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.

### Aqueous & Semi-Aqueous Cleaning System Characteristics

Technology	Washing Systems	Electric Dryers	Wastewater Treatment Systems
Dimensions	Length: 9-50" Width: 12-35" Height: 6-54"	Length: 10-50" Width: 10-40" Height: 5-50"	Length: 30-80" Width: 25-40" Height: 55-70"
Power Rating	6-48 kW	1-66 kW	4-45 kW
Key Inputs Power Other	Electricity Detergents	Electricity None	Electricity Membrane replacements
Key Outputs Solid Waste Air Emissions Water Effluent	None None None	None None None	Oil, grease, solids None Treated water discharged to POTW
Cost Capital Installation Other	\$3000-\$250,000 Minimal Minimal	\$3000-160,000 Minimal None	\$5000-\$300,000 Minimal \$0.5-\$3 per gallon of feed

### 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. In general, semi-aqueous systems are more expensive than aqueous systems; however, the operating cost for an aqueous system is slightly higher. For example, based on a 10-gallon batch system that operates 2000 hours per year, an aqueous process costs approximately \$39,000 to purchase and \$22,000 per year to operate; a semi-aqueous process costs \$55,000 to purchase and \$20,000 per year to operate. The power requirements are about 20 kW for the aqueous system and 15 kW for the semi-aqueous system.

Cost requirements also vary depending on the type of technology used. For instance, a small, single-tank ultrasonic system costs approximately \$3000–\$8000; a multi-stage ultrasonic system costs \$35,000–\$80,000; a dishwasher or agitation-type system costs \$10,000–\$20,000; an in-line conveyORIZED spray system costs \$150,000–\$250,000. Additional costs may arise if dryers or other features such as deionized water rinses or oil-coalescing equipment are needed. For a separate wash, rinse, and dry station, initial costs are \$25,000–\$50,000.

Wastewater treatment systems are also an important part of the capital cost. A large ultrafiltration unit processing 5–10 million gallons of wastewater per year costs \$150,000–\$300,000; a small system costs less than \$10,000. Electricity is only required for pumping wastewater through the system. For a unit processing 0.1–1.0 gallon per minute, the power requirement is 4–10 kW.

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

### **Ultrasonic Cleaning System Characteristics**

Dimensions	Length: 9-50" Width: 12-35" Height: 6-54"
Power Rating	1-48 kW
Key Inputs	
Power	Electricity
Other	Detergent, solvent, aqueous, or semi-aqueous solution
Key Outputs	
Solid Waste	None
Air Emissions	None
Water Effluent	None
Cost	
Purchase	\$3000-\$80,000
Installation	Minimal
Other Supplies	Minimal



Courtesy of Sonicor

## Ultrasonic Parts Cleaning System

### 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.

## **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 then 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, inks, 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 multi-colored 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.



Panel IR Unit for Process Line Drying

### ***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 process line; smaller applications use moveable arch or portable arm-mounted lamps (see figure). 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.



## Electric Infrared Drying & Curing System Characteristics

Dimensions	Length: 6-90" Width: 10-60" Height: 10-90"
Power Rating	8-15 kW per square foot
Energy Consumption	4160 kWh annually*
Key Inputs Power Other	Electricity None
Key Outputs Solid Waste Air Emissions Water Effluent	None None None
Cost Purchase Installation Other Supplies	Panel: \$1000-\$2500 Custom oven: \$10,000-\$250,000 10-20% of purchase cost None

\*Assuming an 8-kW unit used 2 h/d, 5 d/wk, 52 wk/yr.

### Advantages

- Quick, effective drying or 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 routine 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 non-solvent paints, inks, and coatings, short-wave 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).

## **Ultraviolet Curing**

### ***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.



## Ultraviolet Curing

### ***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. The system price varies with the 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.

### **Ultraviolet Curing System Characteristics**

Dimensions	Length: 11-86" Width: 9-55" Height: 18-86"
Power Rating	120-800 watts per inch
Energy Consumption	9600-64,000 kWh per year*
Key Inputs Power Other	Electricity None
Key Outputs Solid Waste Air Emissions Water Effluent	None Ozone None
Cost Purchase Installation Other Supplies	\$1000-\$60,000 Minimal None

\*Assuming a system with four 10-inch lamps operated 2000 h/yr.

### **Advantages**

- Radiation-curable inks and coatings dry quickly, thereby increasing the production rate.
- UV systems work with non-solvent 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 non-wax 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.

## **Outdoor Lighting**

### ***Basic Principle***

Many small businesses benefit from enhanced outdoor lighting through reduced potential for crime, increased employee safety, and improved visibility and attractiveness of the facility.

These benefits are obtained for a relatively small operating cost because, in most cases, outdoor lighting does not contribute to a facility's peak electrical demand. This means that the average energy cost for outdoor lighting (in terms of cents/kWh) is typically less than the energy cost of other improvements.

There are three principal methods for using outdoor lighting in small businesses:

1. Signage on the exterior of the building or illuminated signs near the building to generate attention for the building or the small business
2. General lighting in parking lots, driveways, parking garages, and walkways
3. Facade lighting to increase the visibility of the structure and surrounding architectural features and landscaping

Different lighting technologies are typically used for different applications. Existing lighting systems can often be retrofitted or replaced by energy-efficient lighting systems. In addition, existing lighting systems can be supplemented with new lighting systems to increase safety, security, visibility, and name recognition.

### Typical Outdoor Lighting Applications

Type of Light	Exterior Signage	Parking Garages	Parking Lots/ Driveways	Walkways	Facade and Landscaping
Incandescent	■			■	■
Compact Fluorescent		■		■	■
Fluorescent	■	■		■	■
Metal Halide		■	■	■	■
High-Pressure Sodium			■		
Mercury Vapor			■		

Note: Additional applications are possible for each of the lighting types, but the chart identifies the most efficient applications for each of the light sources. Low-pressure sodium lamps are not normally used in small businesses because of their poor color quality.

### System Description

Mercury vapor, high-pressure sodium (HPS), and metal halide lamps are referred to as high-intensity discharge (HID) lamps. Metal halide lamps and HPS lamps provide approximately 100 and 140 lumens per watt, respectively, while mercury vapor lamps provide up to 60 lumens per watt. Mercury vapor lamps emit a bluish-green light, while HPS lamps emit a yellow-orange light. Metal halide lamps emit a predominately white light. Most HID lamps require a spacing-to-mounting height ratio of 1.0–1.9, which means that the spacing is roughly one to two times the pole height.

Each HID lamp requires a specific ballast to drive the lamp; however, some manufacturers offer metal halide and HPS lamps that can be operated by a mercury vapor lamp ballast. This allows easier conversion from inefficient mercury vapor lamps to higher-efficiency metal halide and HPS lamps. HID lamps are available in a variety of wattages from 35–1500. The HID ballast adds approximately 8–15% to the wattage of the lamp.

Fluorescent lamps are also used as outdoor lighting sources for small businesses. Conventional 4-foot and 8-foot tubes are used in many parking garages and covered walkways. Compact fluorescent lamps are also becoming popular as replacements to incandescent lamps in stairways. Newer T-8 lamps and electronic ballasts are approximately 30% more energy-efficient than older 40-watt T-12 lamps with magnetic ballasts.

Incandescent lamps are the least efficient form of outdoor lighting. However, incandescent lamps are still used as spotlights on signs and as floodlights on building facades and landscaping. The short lifetime of incandescent lamps often has a bigger impact on operating costs than does the additional energy use.

Common controls used for outdoor lighting systems include time clocks, photocells, and programmable controllers.

### Typical Lamp Characteristics for Outdoor Applications

Type of Lamp	Typical Wattages	Initial Lumens/Watt	Avg Rated Life (h)
Incandescent	60-1,500	15-24	750-2,500
Compact Fluorescent	12-35	25-75	8,000-12,000
Fluorescent	20-215	50-100	9,000-20,000
Metal Halide	175-1,500	69-115	10,000-20,000
High-Pressure Sodium	35-1,000	51-140	7,500-24,000
Mercury Vapor	40-1,000	24-60	12,000-24,000

None: Initial lumens/watt includes ballast losses.

### Advantages

Well-designed outdoor lighting systems can offer the following advantages:

- Increased perception of comfort and friendliness
- Increased security for customers and employees
- Reduced accidents in driveways, parking areas, and walkways
- Increased visibility for the facility and the small business

### Disadvantages

Other than installation and operating costs, there are no overall disadvantages of outdoor lighting. However, specific lamps do have weaknesses:

- HID lamps require 2–7 minutes to warm up before reaching full output.

- Metal halide lamps require up to 15 minutes to cool before restrike.
- Special low-temperature fluorescent lamps are required in cold climates to maintain a relatively constant lumen output when temperatures are below freezing.

### **Commercial Status**

All of the lamps described above are readily available from a variety of manufacturers. However, mercury vapor and older T-12 fluorescent lamps are being phased out of production.

Gradual improvements have been made in the efficiency of outdoor lighting systems. In addition, color-corrected HPS lamps are available, as well as improved metal halide lamps that contain incandescent or fluorescent lamps that come on if the power is interrupted.

### **EPRI Information**

Additional information on lighting technologies is available from the EPRI Lighting Information Office, (800) 525-8555.

### **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.

#### ***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.



Courtesy of the Engineering Systems Division of Kinetico Inc., Newbury, Ohio.

## Ion Exchange System

### Ion Exchange System Characteristics

Capacity	30-1800 gal/h
Dimensions	Diameter: 2-12' Height: 6-10'
Energy Consumption	0.07-5.6 kW
Key Inputs	
Power	Electricity
Other	Resins
Key Outputs	
Solid Waste	Recovered metal
Air Emissions	None
Water Effluent	Treated water can be discharged
Cost	
Purchase	\$1000-\$100,000
Installation	Minimal
Other Supplies	Resins

## **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.

## **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-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.



Courtesy of Engineered Systems Division of Kinetico Inc., Newbury, Ohio.

## Electrolytic Metal Recovery System

### Electrolysis System Characteristics

Size	10-100 sq ft
Energy Consumption	0.2-10.0 kWh/lb of recovered metal
Key Inputs Power Other	Electricity Cathodes
Key Outputs Solid Waste Air Emissions Water Effluent	Cathode loaded with metal None Treated or recycled solutions are returned to the metal finishing process
Cost Purchase Installation Other Supplies	\$15,000-\$60,000 Minimal \$0.10-\$3.00/kg of recovered metal

### 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 chlor-alkali 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 of cathode surface area 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 wastewater 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.

## **Membrane Filtration**

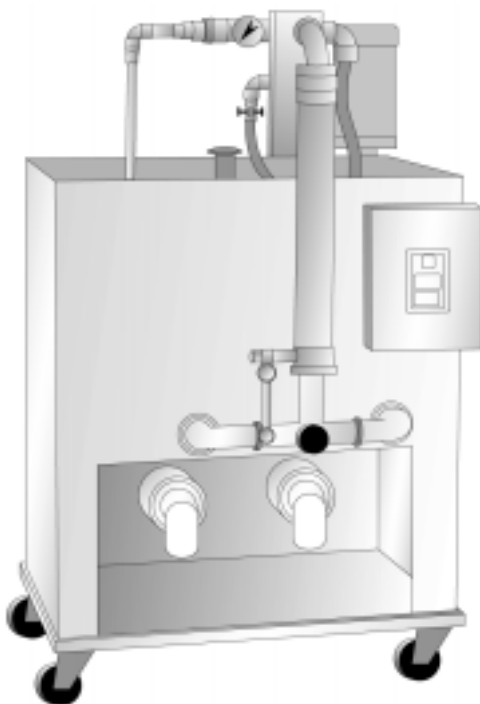
### ***Basic Principle***

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.

### ***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.



Courtesy of Koch Membrane Systems Inc.

## Ultrafiltration Unit

### Membrane Filtration System Characteristics

	Microfiltration	Ultration	Reverse Osmosis
Energy Consumption	1.0-3.0 kWh/100 gal of permeate	1.0-6.0 kWh/100 gal of permeate	1.0-7.0 kWh/100 gal of permeate
Capacity	0.1-10.0 gal/min	0.1-10.0 gal/min	0.1/10.0 gal/min
Key Inputs			
Power	Electricity	Electricity	Electricity
Other	Membrane	Membrane	Membrane
Key Outputs			
Solid Waste	Organics, metals	Oil, grease, solids	Heavy metal, salts
Air Emissions	None	None	None
Water Effluent	None	None	None
Cost			
Capital	\$5000-\$100,000	\$5000-\$100,000	\$10,000-\$130,000
Installation	10-30% of purchase price	10-30% of purchase price	10-30% of purchase price
Operating	\$0.05-\$0.40/100 gal	\$0.05-\$0.30/100 gal	\$0.10-\$0.30/100 gal

## **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 kilowatts of electricity, respectively. In this range, the electricity usage of an ultrafiltration unit is 1.0–6.0 kWh per 100 gallons of filtered water (permeate), the usage of a microfiltration unit is 1.0–3.0 kWh per 100 gallons of permeate, and the usage of a reverse osmosis unit is 1.0–7.0 kWh per 100 gallons of permeate.

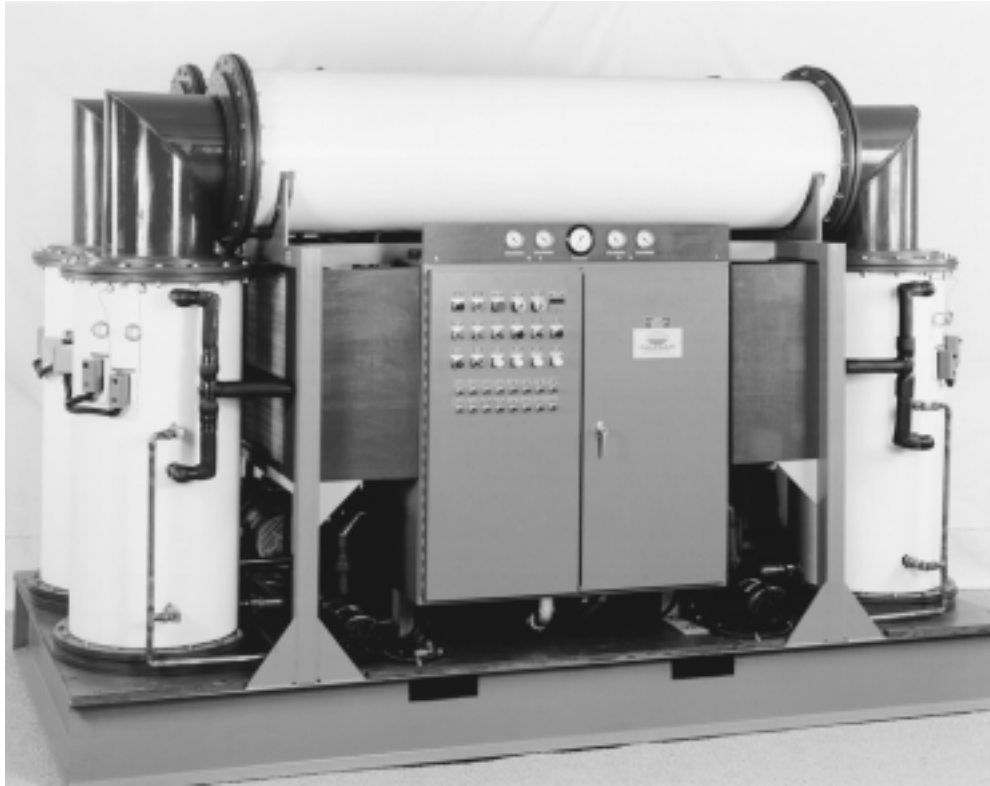
## **Vacuum Evaporation**

### ***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 and 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 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, gold; alkalis and acids; and industrial wastewater.



Courtesy of R. J. Brimo Enterprises, Ltd.

## Vacuum Evaporation Unit

### Vacuum Evaporation System Characteristics

Evaporation Rate	0.01-1.0 gal/min
Dimensions	Length: 18-71" Width: 12-99" Height: 12-115"
Energy Consumption	1.5-20.0 kW
Key Inputs	
Power	Electricity
Other	None
Key Outputs	
Solid Waste	Metal-bearing sluge
Air Emissions	None
Water Effluent	Water can be recycled or discharged to the sewer
Cost	
Purchase	\$7000-\$154,000
Installation	Minimal
Other Supplies	None

## **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. An operation with a 1.0-gpm unit would consume less than 100,000 kWh/yr, assuming an operation rate of 5000 h/yr.

# 5

## RESOURCES

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This section contains three lists: 1) equipment suppliers for the electrotechnologies profiled in this guidebook, by equipment type; 2) EPRI information resources on efficiency technologies; and 3) metal finishing trade associations. Information used to compile these lists was based on a combination of a telephone survey, published reports, directories, buyer's guides, and technical journals. The information was current at the time of publication and is expected to change over time.

### **Aqueous & Semi-Aqueous Cleaning**

#### ***Equipment Suppliers***

##### **American Metal Wash**

360 Euclid Ave., P.O. Box 265, Canonsburg, PA 15317  
(412) 746-4203, fax: (412) 746-5738

##### **CD Nelson Manufacturing Company**

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

##### **Electrovert Corporation**

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

##### **Forward Technology Ind., Inc.**

13500 County Rd. 6, Minneapolis, MN 55441  
(612) 559-1785, fax: (612) 559-3929

##### **Gray Mills Corporation**

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

##### **Jensen Fabricating Engineers**

55 Wethersfield Rd., Berlin, CT 06037  
(860) 828-6516, fax: (860) 828-0473

**Lewis Corporation**

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

**Ramco Equipment Corporation**

32 Montgomery St., Hillside, NJ 07205  
(908) 687-6700, fax: (908) 687-0653

**Ransohoff Company**

4933 Provident Dr. Cincinnati, OH 45246  
(800) 248-9274, (513) 870-0100, fax: (513) 870-0105

**SAS, Inc.**

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

**SONICOR Instrument Corporation**

100 Wartburg Ave., Copiague, NY 11726  
(516) 842-3344, fax: (516) 842-3389

**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  
(414) 894-2293, fax: (414) 894-7029

**Tally Cleaning Systems**

Division of Metfab Engineering, 332 John Diestch Blvd., Attleboro Falls, MA 02763  
(508) 695-1007, fax: (508) 695-6335

**Unique Industries**

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

**U.S. Polychemical Corporation**

Route 45, Chestnut Ridge Rd., Chestnut Ridge, NY 10977  
(914) 356-5530, (800) 431-2072, fax: (914) 356-6656

## **Ultrasonic Cleaning**

### ***Equipment Suppliers***

#### **Blackstone Ultrasonics, Inc.**

9 North Main St., Jamestown, NY 14701  
(800) 766-6606, (716) 665-2340, fax: (716) 665-2480

#### **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

#### **Branson Ultrasonics Corporation**

41 Eagle Rd., Danbury, CT 06813-1961  
(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 Corporation**

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

#### **Forward Technology Ind., Inc.**

13500 County Rd. 6, Minneapolis, MN 55441  
(612) 559-1785, fax: (612) 559-3929

#### **Lewis Corporation**

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

#### **Ramco Equipment Corporation**

32 Montgomery St., Hillside, NJ 07205  
(908) 687-6700, fax: (908) 687-0653

#### **Ransohoff Company**

4933 Provident Dr. Cincinnati, OH 45246  
(800) 248-9274, (513) 870-0100, fax: (513) 870-0105

#### **SAS, Inc.**

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

**SONICOR Instrument Corporation**

100 Wartburg Ave., Copiague, NY 11726  
(516) 842-3344, fax: (516) 842-3389

**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

**U.S. Polychemical Corporation**

Route 45, Chestnut Ridge Rd., Chestnut Ridge, NY 10977  
(800) 431-2072, (914) 356-5530, fax: (914) 356-6656

**Electric IR Drying & Curing**

***Equipment Suppliers***

**Aitken Products, Inc.**

P.O. Box 151, 566 North Eagle St., Geneva, OH 44041  
(216) 466-5711, fax: (216) 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 Corporation**

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

**Dry-Clime Corporation**

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



**Edwin Trisk Systems**

670 New York Street, Memphis, TN 38104  
(800) 261-7976, fax: (901) 274-8355

**Eraser Company, Inc.**

Olivia Drive, P.O. Box 4961, Syracuse, NY 13221  
(315) 454-3237, fax: (315) 454-3090

**Future Cure**

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

**Fostoria Industries, Inc.**

1200 N. Main St., Box 986, Fostoria, OH 44830  
(419) 435-9201, fax: (419) 435-0842

**Glenro, Inc.**

39 McBride Ave., Paterson, NJ 07501  
(800) 922-0106, fax: (201) 279-9103

**Infratech Corporation**

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

**Infratrol Manufacturing Corporation**

646 S. 29th St., Milwaukee, WI 53234  
(414) 671-7140, fax: (414) 671-5088

**IRT Systems**

89 Connie Crescent Concord, Ontario, L4K 1L3, Canada  
(800) 387-3639, fax: (905) 669-1171

**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**

458 Hamburg Turnpike, Wayne, NJ 07470  
(201) 942-7767, fax: (201) 942-5581

**Solaronics**

704 Woodward Rochester, MI 48307  
(810) 651-5333, fax: (810) 651-0357

**Tech Systems**

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

**Watlow Electric Manufacturing Company**

12001 Lackland Rd., St. Louis, MO 63146  
(314) 878-4600, fax: (314) 878-6814

**Ultraviolet Curing**

***Equipment Suppliers***

**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 Systems Corporation**

910 Clopper Rd., Gaithersburg, MD 20878  
(301) 527-2660, fax: (301) 527-2661

**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 Corporation**

20 Commerce Way, Woburn, MA 01801  
(617) 938-3594, fax: (617) 933-8804

**Outdoor Lighting**

***Equipment Suppliers***

**Bairnco Corp.**

2251 Lucien Way, No. 300, Maitland, FL 32751  
(407) 875-2222, fax: (407) 875-3398

**Bieber Lighting Corp.**

970 W. Manchester Blvd., Inglewood, CA 90301  
(213) 776-4744, fax: (310) 216-0333

**Bulbtronic, Inc.**

45 Banfi Plaza, Farmingdale, NY 11735  
(800) 647-2852, (516) 249-2272, fax: (516) 249-6066

**Carlton (Lanson & Sessions Co.)**

25701 Science Park Dr., Cleveland, OH 44122  
(216) 831-4000, fax: (216) 831-5579

**Cooper Lighting Group**

400 Busse Rd., Elk Grove Village, IL 60007-2195  
(847) 956-8400, fax: (847) 956-1475

**Crouse-Hinds Co.**

Lighting Production Div., P.O. Box 4999, Syracuse, NY 13221  
(315) 477-8185

**Doane, L.C., Co.**

55 Plains Rd., P.O. Box 975, Essex, CT 06428  
(203) 767-8295, fax: (203) 767-1397

**Duro-Test Corp.**

9 Law Dr., Fairfield, NJ 07004  
(201) 808-1800, fax: (201) 808-6622

**Federal APD, Inc.**

**Federal Signal Corp.**

24700 Crestview Ct., Farmington Hills, MI 48335  
(800) 521-9330, (810) 477-2700, fax: (810) 477-0742

**Gardco Lighting**

2661 Alvarado St., San Leandro, CA 94577  
(510) 357-6900, fax: (510) 357-3088

**G.E. Company**

3135 Easton Turnpike, Fairfield, CT 06431  
(800) 626-2004, fax: (518) 869-2828

**Hapco Division of Kearney-National, Inc.**

P.O. Box 547-KN, Abingdon, VA 24210  
(540) 628-7171, fax: (540) 628-7707

**Litetronics International**

4101 W. 123rd St., Alsip, IL 60658  
(708) 389-8000 ext 195, fax: (708) 371-0627

**Mason, L.E., Co.**

98 Business St., Boston, MA 02136  
(617) 361-1710, fax: (617) 361-6876

**Philips Lighting Co.**

200 Franklin Sq. Dr., Somerset, NJ 08875  
(908) 563-3000, (800) 631-1259, fax: (908) 563-3975

**Rig-A-Light**

P.O. Box 12942, Houston, TX 77217  
(713) 943-0340, fax: (713) 943-8354

**Sterner Lighting Systems**

351 Lewis Ave., Winisted, MN 55395  
(320) 485-2141, fax: (320) 485- 2899

**Thomas and Betts**

Corporate Headquarters, Memphis, TN 38119  
(800) 888-0211, fax: (800) 888-1366

**Unique Solution/Manville**

515 McKinley Ave., Newark, OH 43055  
(614) 349-4194

## **Ion Exchange**

### ***Equipment Suppliers***

#### **Aquapure Technologies, Inc.**

2224 E. 14 Mile Rd., Warren, MI 48092  
(800) 792-6178, fax: (810) 795-0420

#### **Kinetico Engineered Systems, Inc.**

10845 Kinsman Rd., Newbury, OH 44065  
(800) 633-5530, (216) 564-5397, fax: (216) 338-8694

#### **Memtek Corporation**

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

#### **Osmonics**

5951 Clearwater Dr. Minnetonka, MN 55343  
(800) 848-1750, (612) 933-2277, fax: (612) 933-0141

#### **Serfilco, Ltd.**

1777 Shermer Rd., Northbrook, IL 60062  
(800) 323-5431, (708) 559-1777, fax: (708) 559-1141

#### **U.S. Filter Corporation**

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

## **Electrolysis**

### ***Equipment Suppliers***

#### **Andco Environmental Processes, Inc.**

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

#### **Electrosynthesis Company**

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

#### **Hallmark Refining Corporation**

1743 Cedardale Rd., P.O. Box 1446, Mt. Vernon, WA 98273  
(800) 255-1895, fax: (360) 424-8118

**Kinetico Engineered Systems, Inc.**

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

**Manchester Corporation**

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

**Memtek Corporation**

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

**Safety-Kleen/Drew Products**

1717 Fourth St., Berkeley, CA 9471  
(510) 527-7100, fax: (510) 525-5294

**Membrane Filtration**

***Equipment Suppliers***

**Applied Membranes, Inc.**

110 Bosstick Blvd., San Marcos, CA 92069  
(619) 727-3711, fax: (619) 727-4427

**EPOC**

3065 North Sunnyside, Fresno, CA 93727  
(209) 291-8144, fax: (209) 291-4926

**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  
(708) 513-0550, fax: (708) 513-0551

544 E. Eisenhower Parkway, Suite 150, Ann Arbor, MI 48108  
(313) 761-3836, fax: (313) 761-3844

**Komline-Sanderson**

12 Holland Ave., Petack, NJ 07977  
(908) 234-1000, fax: (908) 234-9487

**LCI Corporation**

P.O. Box 16348, Charlotte, NC 28297  
(704) 394-8341, fax: (704) 392-8507

**Membrex, Inc.**

155 Route 46 West Fairfield, NJ 07004  
(201) 575-8388, fax: (201) 575-7011

**Memtek Corporation**

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

**Osmonics, Inc.**

59951 Clearwater Dr. Minnetonka, MN 55343  
(612) 933-2277, fax: (612) 933-0141

**Prosyst Corporation**

187 Billerica Rd., Chelmsford, MA 01824  
(508) 250-4940, fax: (508) 250-4977

**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

**Vacuum Evaporation*****Equipment Suppliers*****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 Corporation**

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

**Information on Efficiency Technologies**

This list provides EPRI resources on efficiency technologies identified in this guidebook. Copies of publications can be ordered through the EPRI Distribution Center, (510) 934-4212.

***Adjustable Speed Drives***

*Medium-Voltage Adjustable Speed Drives: A Basic Specification Guide*, BR-104420, 1995.

*Adjustable Speed Drives: Application Guide*, TR-101140, December 1992.

*Adjustable Speed Drive Directory, Third Edition*, CU-7544, December 1992.

*Assessment of Electric Motor Technology: Present Status, Future Trends, and R&D*, TR-101264, December 1992.

*Proceedings: Advanced Motors and Drives R&D Planning Forum*, TR-191288, December 1992.

*Environmental Benefits of Adjustable Speed Drive Applications*, TR-100200, July 1992.

***Energy-Efficient HVAC***

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## **Trade Associations**

### **The American Electroplaters and Surface Finishers Society, Inc. (AESF)**

12644 Research Parkway, Orlando, FL 32826-3298  
(407) 281-6441

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

### **National Association of Metal Finishers (NAMF)**

401 N. Michigan Avenue, Chicago, IL 60611-4267  
(312) 644-6610

*Members are management executives, including owners of metal finishing and related businesses.*

### **Metal Finishers Suppliers Association (MFSA)**

801 N. Cass Avenue, Suite 300, Westmont, IL 60559  
(708) 887-0957

*Members are suppliers to the metal finishing industry.*