COMPETITIVE IMPLICATIONS OF ENVIRONMENTAL REGULATION: IN THE METAL FINISHING INDUSTRY

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INTRODUCTION

Metal finishing is a collective term for a group of industrial processes which provided functional and appearance characteristics for surfaces of manufactured products and components. Metal finishing provided a product with a variety of physical, chemical, engineering, and appearance qualities such as corrosion resistance, wear resistance, and brightness. Every manufactured or fabricated product made of metal or having metal components featured some type of metal finishing. As a result, it was one of the most ubiquitous and pervasive manufacturing processes found in the global economy.

As Figure 1 illustrates, metal finishing can be broken down into four general families of technologies -- organic coating, plating, conversion, and removal. For purposes of industrial classification, metal finishing is divided into two general categories. The first is the Electroplating, Plating, Polishing and Anodizing industry is classified under Standard Industrial Code (SIC) 3471 and is comprised of establishments whose primary business is based on these types of finishing processes. Metal Coating and Allied Services, SIC 3479, is the other major branch of metal finishing and includes establishments involved in the application of liquid paints and powder coatings.

INDUSTRY STRUCTURE

Most metal finishing capacity was found within manufacturing companies as one of many operations within a larger manufacturing process. According to a 1993 study of the U.S. Office of Technology Assessment, firms with in-house or "captive" finishing operations comprised an estimated 85%-90% of the number of companies that did some type of metal finishing. The remaining 10-15% of companies constituted what was considered the metal finishing industry -- independent "job shop" establishments that contracted with manufacturers for their finishing needs. Although closely linked to all types of manufacturing, the metal finishing industry was in essence a service industry.

The reason for the existence of the job shop metal finishing industry can be understood by looking at the relationship of metal finishing to the rest of the manufacturing process. Finishing was generally the last operation before sale or assembly. It might have required capital intensive operations but may have only had a minor financial impact on the overall value-added of the product. It also was intimately connected to a wide variety of chemical uses and regulations. As a result of these characteristics, it made economic and manufacturing sense for many firms to outsource their finishing to specialist firms.

Total value of shipments for the U.S. metal finishing industry was over $10 billion by the mid 1990's, which is divided roughly equally between plating and coating services in terms of value of shipments (Table 1). The industry employed an estimated 109,000 people with a total payroll of over $3.6 billion. As a service industry based on demand for manufacturing products, sales were heavily influenced by the economic and market conditions shaping individual manufacturing sectors. As these sectors rose and fell with business cycles, market trends, and general economic conditions, so did the respective demand for metal finishing services. Three market segments -- automotive, electronics, and consumer durables -- were especially influential to the overall health and welfare of the industry (Table 2).

Like many "job shop" industries, metal finishing was dominated by small, single facility companies. The number of metal plating and related facilities decreased 4.3% over a ten year period from 1982 to 1992 while coating and related facilities increased 19.5% over this same period (Tables 3 & 4). The growth of the coating sector was tied to the advancement of powder coating technologies -- the one notable exception in an industry which had historically featured a rather stable process technology paradigm. Overall, the threat of new entrants into the industry was relatively low given the maturity of industry technologies, market saturation in heavily industrialized regions which constituted the customer base, and the barriers created by environmental regulatory policy. However, new firms may have arisen in response to regional growth in manufacturing in particular areas of the country. In addition new firms were expected to originate out of industry to take advantage of expertise in carefully defined and specialized finishing niches -- especially in response to industry outsourcing.

Geographically, metal finishing operations were concentrated most heavily in manufacturing regions which comprised the customer base such as the Great lakes and Mid-Atlantic regions and states like California and Texas. Despite this concentration, in 1992, 35 states had 150 or more employees in plating job shops and 30 states had 150 or more employees in painting job shops. The nationwide presence existed because metal finishing typically was done near the manufacturing base since transportation costs and longer manufacturing lead times were likely to overwhelm any marginal cost savings from using finishers distant from a manufacturing plant.

International Metal Finishing Industry

As in the United States, foreign metal finishing firms provided an essential service to a country's manufacturing base. The particular type of metal finishing capacity found internationally was often intimately connected to the cornerstone export industry of a particular country. For example, Thailand featured significant chrome finishing capacity to finish rolls used in textile production, while the small oil exporting country of Bahrain had an extensive hard chrome finishing capacity to plate gears, pumps and other equipment used in oil extraction.

Besides serving a critical manufacturing infrastructure role, metal finishing was well suited to developing country growth strategies given its often labor intensive nature and comparatively low technology and skill requirements. Development funds from organizations such as the World Bank, US Agency for International Development, and the United Nations had been applied to technology transfer and assistance efforts targeting metal finishing operations in countries like Sri Lanka, Pakistan, Malaysia, Indonesia, and Chile. Trade agencies of industrialized countries also participated in these information and technical assistance efforts to promote the export of domestic equipment and consumable supplies. Moreover, as many multinational manufacturers chose to move fabrication and manufacturing operations offshore to take advantage of cheaper labor, the metal finishing followed. Individual companies in these countries often featured the combination of 1990s process technologies with developing country wage structures. The net result was an explosive growth in metal products manufacturing and finishing in developing countries over the ten years after 1984 -- especially among products that featured high volume but simple finishes (Table 5). In 1992, developing Asian country exports of this type of commodity metal product equaled United States and Japan exports combined.

Comparison of US and Developing Country Establishments

Representative similarities and differences between national and foreign finishing establishments may be highlighted in a comparison of two facilities, one in the eastern United States, the other in Tunisia. At one level, these facilities shared much in common. Both were job shops specializing in copper/nickel/chrome processes on parts with complex geometries. The U.S. facility had annual sales of approximately $5 million while its Tunisian counterpart featured annual sales of approximately 1.5 million U.S. dollars -- roughly equivalent in terms of relative scale with regards to the host country. Both experienced sales growth in the area of 10% annually and were in the process of expanding their finishing capacity. Both also marketed to highly demanding customers expecting superior quality. On the shop floor, the age of process equipment was identical and both used untrained labor for parts racking and maintenance work.

Some notable differences, however, existed in operational and competitive context which were somewhat representative of the differences existing between developed and developing country facilities. The U.S. facility's market was largely comprised of manufacturers within a 150 mile radius. Due to the relative scarcity of competing metal finishing firms, the Tunisian facility served manufacturing facilities all over the Middle East. The U.S. facility with the longer operational history had evolved to feature a dedicated professional on staff for process engineering and process bath control while the Tunisian facility relied heavily on international suppliers for these capabilities as well as troubleshooting and assistance on running parts. The dedication to internal plating control and expertise in the U.S. establishment was also illustrated by plating line managers for each individual process. In contrast, the Tunisian facility had one plant manager that monitored all plating operations. Casting rejects were landfilled in the U.S facility while the significantly higher cost of raw material inputs in Tunisia demanded that rejects be put back into the casting pot and sold to other firms less demanding of quality. Finally, and perhaps most significantly, the U.S. facility had a long and strong family history with a deeply embedded culture about how things were done and how things should be done. The newer Tunisian establishment was run by professional managers who did not have 30-plus years in the science and "craft" of metal finishing. With an extremely strong orientation to the bottom line and little personal attachment to anything but the business itself, managers were fearless about technology and operational changes should their quality and cost concerns be satisfied.

Although many U.S. firms demonstrated one or more characteristics of the Tunisian facility, these contrasts are quite common when comparing U.S. and other developed country facilities with metal finishing operations of developing countries.

Firm Characteristics

In a 1993 survey of metal finishers conducted by the Surface Finishing Market Research Board, total reporting facilities averaged 2.2 plating lines per shop. Steel substrates constituted the majority of surface area being finished (68.2%) followed by copper and its alloys (brass, bronze, etc.), aluminum, and zinc. Average facility plating volume was reported as 2 million square feet/year. Employment within metal finishing job shops could vary significantly depending on the size of the facility. However, the majority of metal finishing job shops had fewer than twenty employees (Tables 3 & 4).

Table 6 highlights several profitability and performance measures for metal finishing operations.

The average U.S. metal finishing facility had a sales volume of approximately $1.1 million with net profits around 5% of sales. Finishing capacity does not seem to have been positively correlated to greater profitability. In the plating sector for 1993, establishments with assets under $250,000 reported better return on assets and profits as a percentage of sales than facilities with assets over $1,000,000. Similar results were found in the painting sector in which the smaller facilities featured some of the best profitability ratios and financial returns. Experts have suggested that the reason for this relationship was that the highly capitalized shops competed in high volume finishing markets which were more competitive and, as a result, featured lower margins. In turn, lower capitalized shops were more likely to be specialty platers and feature higher margins.

Capital availability was an ongoing issue for many metal finishing firms. Total capital expenditures (all facilities) averaged $53,878 for SIC 3471 firms (plating and related) and $65,496 for SIC 3479 facilities (painting and coating) in 1992 . Although varying degrees of capitalization were needed to compete in different plating markets and comply with regulations, the purchase of a major piece of equipment was often equal to or greater than the entire net profit of a facility for a given year.

Workforce skills can vary substantially depending on the type of metal finishing activity. On one end of the finishing spectrum, low value added plating of simple parts may have required little in the way of skilled labor. On the other end, expensive intricate parts, precious metal plating, and/or plating to tight specifications would likely have required a skilled labor force intimately familiar with total quality management tools and statistical process control. Experienced platers and, to a lesser extent painters, were highly valued for the knowledge they accumulated over time. Metal finishing had historically been as much art as science, and years of experience had been invaluable in production and troubleshooting.

The relationship between finishers and their suppliers was a key factor affecting environmental and business performance of the industry. In addition to equipment and materials sales, vendors provided a variety of other support activities including technical support for troubleshooting and engineering, process design assistance, and financial support such as covering switching costs for process chemistry changes. Finishers were heavily reliant on suppliers for information on technology availability and proper operating practices. As process chemistries and equipment became more and more sophisticated (largely as a function of environmental concerns), this dependency was expected to increase in the future.

Competitive Structure of the Metal Finishing Industry

Overall, the metal finishing industry was generally marked by strong rivalries and price competitiveness. For a particular type of finish, the service was largely undifferentiated between providers. If any differentiation did exist or if a demand for certain type of finish increased, incremental investments were made in different finishing processes and chemistries. Even if finishers were strongly tied to existing equipment and treatment systems, surveys of metal finishers have demonstrated a "survivor's will" to move into other markets. Exit barriers were also high as a result of potential site liability and clean-up costs --especially for any finishing facility which had been in existence for more than 15 or 20 years.

Besides the "supply" of firms providing metal finishing services to a given area, the competitive position of individual companies was also likely to be influenced by the relative amounts of "high value added" and "low value added" finishing in their business mix. "Low value added" finishing involved simple parts (often at very high volumes), and simpler plating processes. Markets such as hardware (nuts and bolts), decorative chrome, and tubular steel would fall into this category. Firms featuring a strong low value added finishing element in their business mix typically served a variety of different markets and were flexible enough to finish most anything that did not have special performance or specification needs associated with the finish. These firms competed heavily on price and strived to be the low cost leader.

The general competitive position of these firms was often poor for several reasons. First, there were often many such firms available within a region, all competing on price, which left the entire segment worse off from a profitability standpoint. Customer loyalty was very rare in this segment making technical upgrade more risky. Because of their more precarious profitability history, these firms were also more likely to be "trapped" in older processes. Finally, the segment was susceptible to losing business as a result of trends in offshore manufacturing. As more companies fabricated and assembled offshore to take advantage of cheaper labor, the metal finishing operations followed.

High value added finishing featured one or more characteristics which made the finishing activity less of a commodity service. Finishing expensive parts, finishing difficult or intricate parts, finishing with precious metals, or finishing to tight product specifications were examples of this class of finishing. Electronics, medical devices, and aerospace would be examples of customers for this segment. The competitive and financial position of finishers with a larger business mix in this segment was generally more positive in that specialty; high quality plating could provide an important level of differentiation from other finishers. Because of the high value nature of the products which were finished, their relationships with customers were likely to be closer, longer term, and more loyal and supportive. These finishers were more likely to specialize in a few types of finishes and be able to supply manufacturers outside their immediate area.

Competing Technologies

As a collective set of diverse technologies, metal finishing had no competing technologies although individual technologies and processes within the set may have been intense competitors. However, an area of technology change which had substantial implications for the long term health and welfare of the metal finishing service industry was alternative substrates. In markets such as the automotive sector, trends toward fabricated parts made of plastics rather than steel had already left an imprint on the metal finishing industry. This negative impact was neutralized in part by an increase in outsourcing as more manufacturers looked to contract out remaining metal finishing needs. However, technology developments in engineered plastics, ceramics, and alloys may have reduced the need for metal finishing in certain markets. In addition, advances in primary metals manufacturing were occurring in which desirable finish qualities were being engineered into the metal itself.

ENVIRONMENTAL, HEALTH AND SAFETY PRESSURES

The metal finishing industry was second only to the nuclear industry in terms of the number of applicable regulations and reporting requirements. It was also one of the most challenging to classify since 46 different metal finishing processes were regulated under metal finishing standards featuring different operational steps, inputs, and outputs. It was also common for several of these metal finishing processes to be combined in one overall finishing process. For example, a part may first be etched, then plated, then receive a conversion coating. The variety of possible substrate/finish combinations added to the complexity. Since metal finishing processes generate pollutants and emissions specific to each process, environmental pressures and responses varied from firm to firm.

For purposes of reviewing environmental issues, regulatory pressures and the subsequent impact on technology innovation and competitiveness, the following sections will focus specifically on plating operations -- one of the most common metal finishing services and one of the most economically and environmentally significant.

Environmental Risks Analysis: Plating Operations

Plating is the deposition of one or more metal coatings onto a metal substrate and is a very flexible method for providing substrates with many desirable finish properties. The most common set of plating processes were aqueous based processes in that they featured the use of process baths and rinse steps. Issues of environmental concern generally fell into the following categories:

Chlorinated hydrocarbons and halogenated solvents were commonly used materials in surface preparation to clean and degrease the part before the plating process. These materials caused air pollution through evaporation and may have undergone chemical changes in the atmosphere affecting smog creation, ozone depletion and global warming potential.

Acids and caustics were ubiquitous in plating operations. Acids were used in the surface preparation stage to remove oxides in preparing the part for plating. They were found in stripping operations to allow rework of improperly plated or out of specification parts, and used to adjust wastewaters prior to discharge. Process solutions themselves were frequently acid-based. Caustics were also found throughout metal finishing operations. Many process solutions were high pH chemistries, and large amounts of caustic hydroxides were used in wastewater treatment.

Metals were primary materials of concern in plating operations. Commonly plated metals included zinc, lead, nickel, chrome, copper, silver, and tin although many other metals and metal combinations were found. Metals differed in their relative degrees of human and aquatic toxicity, but their presence in plating discharges had been the primary focus for industry regulation. Some metal plating, such as electroless copper and those processes using chrome in its hexavalent state, created issues of air concern as well.

Cyanides were compounds found in many plating chemistries used to keep metals in solution. Cyanide-bearing wastewaters posed significant human health and toxicity issues and were required to undergo a destruction process in the facility wastewater treatment system before being discharged.

Other organic and inorganic compounds were used in process chemistries to modify or enhance the properties of the metal deposit or improve the performance and preserve the life of the bath. Ammonia and formaldehyde were examples of such compounds and were commonly released to the air through agitation of process solutions.

Treatment chemicals were also used in the facility wastewater treatment system to alter, destroy, and/or facilitate the removal of materials of concern prior to discharge. Examples included sulfur dioxide gas which was used to reduce hexavalent chrome and chlorine gas which was used to destroy cyanides.

The possible combinations and permutations of these materials in plating operations resulted in a large universe of potential environmental hazards.

Regulation

The quantities of water use and releases in metal finishing and the potential potpourri of materials to be found in these discharges made water pollution concerns the historical starting point for environmental regulation in the industry. The first nationwide attempt to regulate the use and release of water in metal finishing was the Federal Water Pollution Control Act (FWPCA) amendments of 1972. Prior to the FWPCA, some states and municipalities regulated water resources through a variety of local laws and ordinances. The passage of an amendment to the FWPCA in 1977 known as the Clean Water Act finalized the legislative underpinnings for the regulatory context in which metal finishers operate today.

Since that time, the regulatory context has expanded dramatically to include air and hazardous waste issues and non-production aspects of metal finishing operations. As time progressed, regulations in all these areas increased both in scope and complexity. A further complicating factor was that individual plating operations were usually regulated by state and local authorities who had the ability to set more prescriptive standards than those contained in Federal law.

Wastewater Discharges

Wastewater discharges from plating facilities were regulated under two sets of federal guidelines (Table 7). One set of regulations applied to electroplating job shops that began operation prior to September 1982 and were indirect discharges (those who discharge to sewer systems and publicly owned treatment works or POTWs). These regulations included concentration limits and alternative mass-based limits for discharge of metals, cyanide, and total toxic organics. The mass-based standards were based on production as measured by area of parts processed. The other set of guidelines applied to any facility that was a direct discharger (discharging directly to surface waters), captive operations, and job shops that began operations after August 1982. These regulations were concentration-based standards that limited the discharge of metals, cyanide, and total toxic organics for indirect discharge facilities and, in addition, oil, grease, suspended solids and pH for direct dischargers. As Table 8 illustrates, a facility's regulatory compliance profile was also influenced by the amount it discharged.

Currently evolving requirements exacerbated the regulatory pressures pertaining to the water discharges of metal finishers. Lower concentration limits increased the performance requirements of facility wastewater treatments systems requiring retrofits or new technologies. Mass load limits eliminated dilution as a conformance tool. Aquatic toxicity limits went beyond concentration or mass based limits and required special assessments of discharges. A POTWs special requirements for discharge may result in more stringent standards "upstream" for wastewater sources. Finally, new air regulations were prompting the use of control technologies and alternative cleaning systems which placed greater demands on wastewater management system.

Land Disposal

Plating operations generated large volumes of wastewaters which were treated resulting in a residual sludge which was regulated as hazardous waste. The enabling legislation for regulating hazardous waste -- the Resource Conservation and Recovery Act (RCRA) -- created a regulatory approach different from other environmental regulatory systems in that it was not triggered by the direct activity of the waste generator (discharging wastewater or air emissions) but rather by the special characteristics of certain waste materials.

Metals and cyanides were regulated based on the concentration of materials of concern found in the waste. Plating operations shipped these sludges to disposal facilities who tested the waste. Should the concentration have exceeded the permissible limits, the disposal facility would have further treated the waste until it met disposal standards and billed the facility for the additional treatment required.

Air Releases

The Clean Air Act Amendments of 1990 included a list of 189 substances that were to be regulated as hazardous air pollutants (HAPs). Substances on the HAP list of interest to metal finishers included compounds containing cadmium, chromium, lead, and nickel, and most organic solvents commonly used in surface preparation. An extremely complex categorization and classification system ultimately determined how a facility would be regulated and what the permissible emissions of these materials were. Issues affecting the air regulation profile included the amount of emissions, type of processes, size of operation, and whether the operation was new or existing. It has been estimated that the necessary assessment and consulting costs just to apply for a permit ranged from $15,000 - $30,000 for a facility.

Pressure to reduce or eliminate solvent cleaning was also generated through the Montreal Protocol which restricted the production and use of ozone-depleting chemicals. Several ozone depleting substances had been used as solvents but were targeted for complete elimination resulting in the need for cleaning system retrofit or new technologies.

Other Regulations

Plating operations were also subject to several other regulatory burdens as a result of the amount of hazardous materials used in and resulting from their processes. Right to Know laws which involved public reporting on uses and releases of toxic chemicals may have applied to larger facilities. Superfund liability was a particular issue of concern -- especially for older plating operations -- since a facility was liable for any site contamination even if it occurred as a result of practices prior to the promulgation of the regulation. Occupational Safety and Heath (OSHA) laws were another body of regulation having substantial impact on finishing operations. Plating presented a potentially hazardous work environment given toxic air releases from process operations; exposure to acids, caustics and hot baths; and a work environment featuring wet floors, moving equipment, and transfers of a variety of chemicals and liquids. General management and reporting requirements in all these administrative areas added to the labor cost burden for finishing operations.

Comparison of Regulations Across Other Nations

Variations existed among countries for materials and metals standards, but the scope of regulated substances was relatively uniform among developed countries. This similarity extended to developing countries as well whose fledgling environmental protection approaches often mimicked industrialized country standards.

Comparative disadvantages for U.S. firms that finished parts typically arose out of the regulatory and enforcement process rather than the standards themselves. Developing countries typically lacked both a meaningful enforcement mechanism and trained inspectors with appropriate equipment. As a result, the strict effluent standards had little meaning as far as facility operations were concerned, and little attention was given to the operating conditions of the permit or the proper use and maintenance of whatever pollution control measures may have been in place. As an example of this inattention, in two establishments visited in 1995 by U.S. consultants in different developing countries, the settling basins for water discharge had been inactive for so long that palm trees were flourishing in them.

Reporting and paperwork processes that placed such significant demands on U.S. finishers were largely absent in developing countries. Moreover, capital was far more likely to be tied up in environmental control technologies among U.S. finishers. The competitive disadvantage was not limited only to developing countries. Environmental compliance was estimated to have reduced electroplating job shop profit by 30% - 50% in the United States compared to an average of 17% estimated by representatives of other developed nations at an OECD workshop in the mid-1990s.

INNOVATION IN RESPONSE TO ENVIRONMENTAL PRESSURES

Since the basic chemical principles of metal finishing remained unchanged, the core processes of plating have remained largely unchanged over the years. A general process flow diagram of a 1940 operation would appear markedly similar to that of a 1995 facility. Most of the technology advances and innovations in the industry were directly related to environmental regulatory pressures emphasizing materials control, management, recovery, and reuse. A metal finisher may have had several possible technology avenues available to gain compliance, and industry "winners" and "losers" were largely determined by how well these technology decisions were evaluated and implemented.

Technology innovation in the industry originated from two primary sources: federal government research and industry equipment and material suppliers. In 1995, Federal defense, energy and EPA labs sponsored over $38.5 million in research and technology diffusion projects targeting metal finishing. Although these projects addressed all aspects of environmental performance, much of the research was focused on sophisticated, "next generation" finishing technologies as opposed to addressing the more immediate needs of the commercial metal finishing industry. The research and development activities of chemical and equipment suppliers were far more oriented to small business contexts and issues. Innovation among these firms was directly linked to the regulatory pressure points and issues that the metal finishing firms had to address.

Innovations in metal finishing can be grouped into four general areas:

Process Control and Optimization Innovation

Comprised of good operating practices and process management techniques rather than "hard" technology and equipment, process control and optimization were "self-innovations" and critical issues for metal finishers. Careful understanding and control of critical process parameters (temperature, flow rates, contaminant control, pH, density, etc.), optimization of rinsing practices, and process modifications (e.g. extended drain times and good parts orientation) were fundamentals in reducing wastes and minimizing the environmental effects from plating operations. The "technologies" associated with these activities were quite simple and included valves, drain boards, spargers, flow restrictors, and sensors. Adequate use of these techniques created a foundation to get the maximum benefit and potential of alternative technologies described below.

Recovery and Regeneration Equipment

Recovery technologies were used to capture and separate plating metals and chemicals from rinsewaters and concentrate them. If recycling these materials back to the process tanks was technically feasible, regeneration technologies often had to be used in tandem to remove contaminants and otherwise restore the necessary properties of the solution before reintroducing the material back to the process tank. As a result, the useful lives of the process baths were extended, sometimes indefinitely. Recovery technologies had a direct environmental benefit in that they served a pretreatment function for the facility wastewater treatment system -- reducing the metal and chemical loadings of process rinsewaters prior to their final treatment and discharge. Some facilities sought to employ recovery technologies and reuse process rinsewaters to become closed loop or "zero discharge" facilities. Successful closed loop engineering eliminated the need for wastewater treatment systems.

Recovery equipment was a well established set of technologies among finishing operations. Supplier innovations focused on improving the recovery efficiency, effectiveness, durability, and operating "friendliness" of these systems. Industry surveys noted that their use within finishing operations was frequently plagued by technical, design, maintenance, and operating problems. A study by the National Center for Manufacturing Sciences noted that 30-40% of recovery efforts had not been successful. However, their secondary use as "pretreatment" for the facility wastewater treatment system made this set of technologies an important technology element for many plating operations.

Process Chemistries

Innovations also occurred in the development of new, environmentally preferable process chemistries. Many of the innovations involved existing and well established process solutions which could have been reformulated in some way to lengthen their useful life, make rinsewaters easier to treat, or otherwise reduce their potential environmental impact (e.g. low cyanide chemistries). At the other end of the innovation spectrum was the development of new process chemistries to meet one or more finishing requirements. Three particular materials used in plating -- cyanide, cadmium, and chrome -- were the focus for most of substitution because of the strong regulatory drivers associated with each material.

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

Of all the areas of innovation, material substitutions were demonstrated to be the technologies most fraught with implementation barriers since the status quo was nearly codified either informally through customer acceptance and existing investments in recovery and concentration technologies, or formally through customer specifications which demanded the use of specific materials. The status quo was best overcome when regulatory drivers were pointing toward a complete "sunsetting" of materials of concern.

Process Equipment

In response to concerns arising from solvent based cleaning and degreasing operations, a variety of aqueous and semi aqueous based cleaning systems were developed. These systems were most commonly based on the use of alkaline cleaners to remove the materials and soils. The appropriate technology choice was a function of the type of production (intermittent vs. continuous high production), and the type of cleaning concern (oil and grease, metal chips and cutting fluid, polishing compounds, etc.). Additional technology developments within cleaning included microfiltration equipment to regenerate and extend the lives of aqueous cleaning baths.

Advances also occurred in vapor deposition technologies which plated without the use of solutions or baths. This set of "dry" technologies involved the passage of a metal coating material from a solid phase into a vapor transport phase and then back into the solid phase on the substrate surface. Since these technologies (as a group) could be used for nearly any metal coating material, and because they did not utilize bath solutions or feature wastewater streams, they became increasingly important in a number of industrial applications. From a production standpoint, very high capital costs, lower throughput rates, and greater energy intensity had put vapor-phase methods at a disadvantage when compared to traditional solution based processes. However, technology advancements were likely to increase the number of applications in which vapor deposition became an environmentally and competitively preferable technology.

The primary environmental benefit from these vapor deposition systems was the near or complete elimination of metalbearing water wastestreams. As to be expected, eliminating water wastes was not without environmental trade-offs. Energy use was a primary consideration and many reactants used in the system often had corrosive or toxic properties. However the ability to control these risks and the elimination of water media issues made these systems generally recognized as environmentally preferable.

COMPETITIVE POSITION OF INNOVATING FIRMS

Because of the demands environmental regulations placed on metal finishers, innovation was a necessity rather than an option for the industry. The challenge for metal finishers had been to identify and invest in the technology mix that led to compliance assurance in the simplest and most inexpensive way possible. This mix differed from facility to facility since every firm faced a unique set of circumstances as a result of the types of finishing done in the facility, finishing markets served, and the specific regulatory context. The appropriate strategy for a given firm may have included elements from all four innovation areas and additional investment in control equipment.

The metal finishing facility cost structure demonstrated the significance of these choices. Table 9 describes average environmental management cost elements for plating facilities with over 20 employees. Industry estimates in the mid-1990s placed environmental management costs at 10%-14% of sales for U.S. job shop facilities. Within this cost structure, management of water use and release was the primary issue and the focus for most innovation. In a 1993 survey of metal finishers, 89% identified wastewater discharge as their primary environmental management problem. Overall, 62% of annual plating industry environmental management operating cost expenditures and annual pollution abatement capital expenditures were directed towards water media protection (Table 10).

A 1994 survey by the National Center for Manufacturing Sciences found that the average capital cost of a facility wastewater treatment system was over a quarter of a million dollars. In wastewater treatment, a number of unit operations may have had to be purchased to tailor the system to the facility needs. Treatment systems typically included at a minimum pH adjustment, hydroxide precipitation to remove metals, and some means of dewatering the resulting sludge to minimize the volume of hazardous waste. Depending on facility needs a variety of other elements may have had to be purchased such as chrome reduction and cyanide oxidation processes. Annual operating costs would have varied widely depending on the sophistication of the system, flow rates, and concentration of pollutants entering the system, but were comprised of three major elements: labor, treatment chemicals, and sludge disposal. The cost of treatment chemicals in plating facilities could have been over half the annual operating costs for a wastewater treatment system, and the total annual operating costs for wastewater treatment was frequently one half or more of the original capital cost of the system.

Most first level innovation efforts focused on a large portfolio of process optimization practices, although these approaches would still have required water treatment activities. To completely avoid expensive and administratively burdensome water treatment, two larger scale and capital intensive strategies were 1) investment in recovery and water reuse system technologies to become a "closed loop" or zero discharge facility, and 2) investment in "dry" vapor deposition processes which did not use process baths or rinses.

Competitive Position of Closed Loop Facilities

Since no two plating facilities were exactly alike, the technologies, strategies, and accompanying investments needed to close the loop differed from facility to facility. Some metal finishing processes, like hard chrome plating, lent themselves to zero discharge strategies far more readily than others. As a general rule of thumb, zero discharge strategies were most often found in smaller shops featuring simple manual processes that could have operated without discharge if provided good process control. If the shop was large and/or featured a larger diversity of metal finishing processes and/or entailed complex plating processes, the technology needed to close the loop would have needed to be more sophisticated and have required greater capital investment.

Unlike water treatment equipment, the technology associated with closed loop systems was an integral part of the production process itself. The water balance, dragout rate, and recovery/regeneration equipment comprised an interrelated system. This highlights a critical issue in the zero discharge strategy: the need to optimize the existing plating process through source reduction efforts in modified rinsing practices, dragout reduction, impurity control, and good housekeeping before technology investments were made. Without a preinvestment in optimizing operations, the success of the zero discharge effort was endangered and the associated technology cost escalated rapidly since larger capacity systems had to be employed. One estimation holds that a pursuit of zero discharge without upfront process optimization could have cost a facility 2-5 times more than conventional end of pipe treatment.

Assuming the technical feasibility of closed loop processes and the implementation of in-process efficiency and waste minimization projects, the cost and competitive benefits of a zero discharge strategy could have been substantial. Key cost reduction areas were water use (often from 90-95%), sewer costs, sludge disposal costs, chemical treatment costs, raw material costs, and permit fees. For many facilities the regulatory benefits outweighed the direct cost savings since the administrative burden of such activities as permit modifications and TRI reporting were a significant drain on human as well as financial resources. Production and quality benefits could also have been achieved since the recycling and purification of wastewaters may have resulted in water input quality which exceeded that of city water, thereby reducing reject rates and downtime. The operational disadvantage of closed loop was the loss of flexibility that a treatment system provided an exposure to production risks and higher costs should events (such as unexpected process solution contamination) occur. Such concerns reenforced the demand of superior process control and management in conjunction with this strategy to create a possible source of cost advantage.

As an example of the potential closed loop systems hold, the Robbins Company of Attleboro, MA installed a closed loop water treatment and recovery system in 1988. Annual savings in 1989 were comprised of $18,000 in water use, $8,000 in water treatment chemicals, $14,000 in hazardous waste disposal, $26,000 in laboratory analysis costs and $5,000 in regulatory fees for a total of $71,000 and a payback of 1.69 years. More significantly, Robbins avoided having to make an estimated $500,000 upgrade in their conventional wastewater treatment system to remain in business which would have also entailed an additional $120,000 in annual wastewater treatment costs.

While the recovery system and technology components received much of the attention, it was upfront source reduction and process control efforts to reduce metal content in wastewater which made the strategy economically and technically feasible for the company. Fundamentally, Robbins' real source of cost advantage was process optimization which enabled the use of new technology.

Competitive Position of Vapor Deposition Facilities

As described earlier, the application-specific nature of metal finishing makes direct comparisons of finishing technologies difficult. This is especially true in comparing traditional plating process and vapor deposition or "dry" processes whose applications have limited amounts of overlap. Deposition rates, desired deposit properties, and type of substrate may have demanded the use of either plating or vapor deposition systems.

Where there was overlap and a legitimate choice of technology use, the cost and manufacturing implications were typically stacked significantly in favor of existing electroplating processes rather than vapor deposition technologies. Although cost differential would be a function of many factors, experts have estimated that a general cost ratio between vapor deposition and traditional electroplating is 10:1.

As an example, a computer disc manufacturer looking to produce one million discs per month examined and compared cost elements in reviewing the technology options. Equipment investment for vapor deposition totalled approximately $3 million plus an additional $1 million for a "clean room." Plating line equipment and solution would be approximately 1/3 as much and would not require a specially controlled operating environment. To achieve targeted production rates, the vapor deposition process would require 3 shifts, seven days a week. Moreover, every fourth shift would require downtime for maintenance. A plating process could accomplish the work in only two shifts, five days a week with significantly less down time. On the raw materials side, the vapor deposition source computed to a cost of $439/lb. In contrast, anode material for plating would cost $.72/lb. Intangibles, such as the need for worker training upgrades to manage and maintain far more sophisticated equipment, were not included. Yet, despite the overwhelming manufacturing cost advantages of traditional electroplating, the company chose to implement vapor deposition because of the avoidance of working with and disposing of plating chemicals and the 500,000 gallons of water needed daily for this quantity of electroplating throughput.

In general, even though environmental management and waste minimization costs would be reduced -- perhaps substantially -- from using the cleaner vapor deposition processes, these savings would not offset the substantial differences in capital investment and operating costs. Any immediate competitive advantage for vapor deposition adopters was more likely based in being removed from a burdensome regulatory loop. Free from discharge regulations, manufacturers may have been able to act more quickly in response to changing market and production conditions. Competitors under water discharge regulations facing potential non-compliance may have been limited in their ability to react as a function of being held hostage to their existing permit conditions and the potentially protracted process of changing permits.

The comparison suggests that any movement from plating to vapor deposition -- where a choice was possible from a technical and production perspective -- would most likely have been pursued by larger manufacturers who could have afforded the significant capital investment, whose captive finishing operations represented a relatively small share of the overall manufacturing cost structure, but who saw value in being removed from water discharge regulations. Experts do not see vapor deposition making immediate significant inroads into traditional job shop and commodity plating markets because of the operating cost structure and the prohibitively expensive nature of the technology.

EFFECT OF ENVIRONMENTAL REGULATION ON INDUSTRY

Because technical adoption in metal finishing was so application specific, the general competitive dynamics of the industry as a whole were largely unchanged by individual innovations. A major breakthrough (e.g., in finish chemistry) would likely have resulted in some tremors within a specific finishing niche, but rapidly have been adopted by others whose customers would permit it, and have little consequence concerning the competitive structure of the industry as a whole.

In general, some of the competitive advantage implications among companies have already been realized. Some metal finishers have suggested that a window of opportunity existed earlier as environmental regulatory trends pointed toward the issues and types of investments which would be needed. Those companies that made these investments in materials recovery, materials regeneration, and process optimization at that time were then better positioned than those that delayed or ignored the warning signals. The work of the metal finishing sector of the EPA Common Sense Initiative reflected this in that the industry was segmented based on environmental performance for purposes of analysis.   Actions plans were being developed to reward those companies that progressively looked ahead in past technology investments and "phased out" the problem finishers who avoided environmental investments but would potentially drag down the reputation of the industry. In some respects this consolidation was essential for the success of high performing companies since additional business was needed to cover the expenses from the amortization of this additional, and often costly, equipment.

A more subtle dynamic regarding technology innovation and its effects on the industry may have been seen in the willingness of firms in the industry to adopt new technologies. As noted earlier, technology adoption in the industry was marked by remarkably high failure rates.   Examples existed around the country of firms investing significant amounts of capital in environmentally related equipment which did not perform to expectations or achieve the needed results. The result of these experiences is believed by many experts to have made metal finishers generally more skeptical about new process technology adoption.

Although technology innovation has had some effect on the industry and competitive advantage, environmental regulatory issues themselves and their associated administrative burden have had far more influence. These issues have impacted on finishers and related industries differently.

Metal Finishing Job Shops

By definition, job shops were mostly insulated from international competition issues since they were service firms providing finishing needs for regional manufacturers. Exceptions to this might have been found in areas along country borders where the manufacturing base could be served by firms in two countries.

As described in an interview with a plating facility manager in El Paso, TX whose firm specialized in automated barrel plating of copper, tin, and nickel for industrial markets, the potential loss of business from environmental regulatory discrepancies was seen as less of a threat than might at first have been expected. It was recognized that current lack of enforcement combined with lower labor costs may have resulted in some finishing business moving across the border. However, the conclusion was that these comparative cost disadvantages were more than offset by several competitive factors favoring U.S. based operations; namely, lower cost of chemical inputs, infrastructure support such as assurance of electricity for operations, quality of water inputs (essential to low reject plating and lower operating costs) and capital availability. Moreover, the facility manager believed that any environmental advantage is likely to cease to exist over the next two years as Mexican government enforcement activities accelerated and Mexican companies needed to invest in the same environmental systems and controls already in place in U.S. firms. Competitive advantage was likely to remain with Mexican facilities primarily for plating operations which were very labor intensive.

Competitive advantage among domestic metal finishing job shops was largely determined by the amount of wisdom found in operations management and in choosing an appropriate technical path. As noted earlier, the competitive fortunes of domestic firms may have already been cast as a result of past investments and decisions. Interviews with job shop managers suggested that those firms that anticipated environmental trends, worked to optimize processes, and carefully evaluated capital expenditures in this area were positioned to gain business both from increased outsourcing activity as well as to take business from defunct (or soon to be defunct) shops. From a profitability standpoint, this capture of new business was essential since more customers were needed to amortize the costs of the investments made in environmental and process technologies.

Environmental issues were not the sole set of factors leading to decreases in finishing job shops. Increasing quality demands, retirements of founders, and the thinning of manufacturers' supplier bases also contributed to industry consolidation. Environmental issues created additional costs and administrative burdens for the job shop industry but it is difficult to isolate the impact of environmental pressures from these other factors.

Captive Operations

The competitive implications for manufacturers or fabricators with captive metal finishing operations was much more ominous than for job shops since the environmental expenditures were fundamentally linked to the overall manufacturing cost structure. Already placed at potential competitive disadvantages with international competitors because of labor costs, captives face the additional cost burdens of environmental management that could be the factor that tipped the scales in favor of international competition or moving the manufacturing/finishing operation overseas.

Captive operations most likely to be impacted were those featuring simple fabrication, higher labor content, and low value added metal finishing requirements. However, global trade dynamics were such that even the manufacturing and finishing of sophisticated, high value added products were expected to move overseas. Many examples exist of major U.S. manufacturers agreeing to site manufacturing operations in foreign countries to gain access to markets and in return for contract assurances in the host country. As in job shop operations, the environmental management considerations can be just one of a complex set of factors affecting decisions regarding where manufacturing operations are to be sited and, as a consequence, where the metal finishing will be as well.

Although some outsourcing was returning back to manufacturers because of quality and delivery problems, metal finishing outsourcing was expected to continue -- especially for those firms whose finishing processes were not an integral part of the value added for the overall manufacturing process. Another new set of regulations -- the proposed Metal Product and Machinery Regulations --would encourage further outsourcing. These regulations resulted in substantially tighter discharge standards for many captive operations and were expected to cost $500,000 to $750,000 for a small-medium sized facility with finishing operations. Although job shops would not be affected by these standards, it would set a baseline likely to be duplicated in future regulatory actions targeting job shops.

Supplier Industry

Environmental pressures have strongly influenced the consumable materials and equipment suppliers industry. Environmentally-preferable process chemistries and recovery equipment have existed in the industry for many years, but rounds of new regulatory requirements and standards tightening created spurts in innovation as a means to address these pressures. In 1995, Finishers Management magazine noted that the top 10 industry advertisers featured environmentally-related technologies.

The metal finishing supplier industry was comprised of three primary segments -- chemistry/consumables, process equipment, and treatment systems -- each of which continually innovated as a result of environmental issues. Although there were exceptions, little in the way of integration existed among these suppliers as different sciences and disciplines are associated with each area. Equally important, as the chemistries and equipment itself were the accompanying engineering, consulting, and other customer services that suppliers provided and which were in high demand among metal finishers. A trusted supplier created a significant amount of loyalty highly valued by finishers who were bombarded with myriad potential product offerings and substitutes. Obtaining inroads into markets required capturing this trust element and being able to provide products tailored to quite narrow applications. As a result the supplier industry was marked by large numbers of mergers and acquisitions which enabled firms to utilize existing marketing and distribution networks and capture proprietary technology without significant R&D expenditures.

New entrants to the industry continued to occur. Some entrants came from completely outside of metal finishing as a result of expertise in a related process or chemistries. For example, one company with experience in flocculants -- chemical aids which encourage particle growth and assist in the wastewater treatment -- had begun marketing to metal finishing markets. Small chemistry suppliers also continued to arise in response to niche markets or specialty needs in a particular type of plating. It has been suggested by industry experts that these entries were facilitated by the mergers and consolidation of larger suppliers whose close customer bonds and customer service tended to suffer as a result of growth.

Supplier innovation was also being directed to compete with alternative vapor technologies in high value-added, sophisticated finishing markets whose "dry" features made them attractive to consider. Several superior aqueous-based engineering coatings were developed to compete directly with vacuum coatings.

The supplier experience in the United States has been echoed in other supplying nations such as Germany and Japan. Regulatory policies and "targeted" materials have resulted in process innovations which are exported internationally. Zinc alloy processes, a key alternative to cadmium plating, originated in Japan. There was general consensus among the supplier industry representatives that those countries featuring the most stringent standards were those which led in metal finishing technology innovation. There was also consensus that the U.S. exported more plating-related technology than imported. However, the innovations were often dependent on a regulatory system forcing their use. As a result, the finishing industry gained no competitive advantage from having this domestic capacity.

SUMMARY

The metal finishing industry was one of the most highly regulated industrial sectors of the national economy and was subject to intensive competitive and policy pressures. Government and environmental policy had substantial impact on the structure and competitive dynamics of the metal finishing industry and strongly influenced how individual facilities made decisions. However, the development of environmentally preferable technologies was a very minor issue in shaping overall competitive context and was one of the least influential factors affecting industry structure. Several fundamental structural, production, and economic issues suggest why this is so.

- The feasibility of process technology adoption was extremely application specific -- innovation would not result in sweeping, cross cutting change among large groups of finishers.

- As a service industry, the use of particular technologies and finishes were codified formally in specifications or informally through customer acceptance preventing innovation.

- Many of the innovations were completely cost prohibitive to an industry dominated by companies with low profit margins and scarce capital.

- Other process innovations, while financially feasible, may have conflicted with existing equipment infrastructure or conflict directly with quality and throughput demands.

The more significant implication of environmental policy is how regulatory requirements have completely transformed key success factors in the industry. In the past, successful metal finishing firms featured experienced finishers whose craft and "know how"(ability to reduce labor costs, and general recognition among customers) were invaluable. Successful firms also demonstrated an ability to do a wide variety of finishing to ride out business cycles and downturns in specific industrial markets. As a result, successful firms tended to be larger shops gaining economies of scale in production and wastewater treatment.

Because of government policy and regulatory pressure, the sources of competitive advantage (and conditions of business viability) were changing substantially. Primary sources of advantage were knowledge and skill based factors allowing firms to make better process and technology decisions. Investments in labor skill development and process control were essential in order to optimize processes to the greatest extent possible to maximize process efficiency and minimize waste treatment costs. Specialization -- knowing and doing a few processes superbly well -- minimized environmental risk exposures, reduced the number of wastestreams a facility had to treat, and provided a potential source of differentiation from other finishers. The ability to create, analyze, and evaluate processes independent of suppliers and a modernization of management systems both served to link quality assurance concerns to environmental effects. Finally, the ability to access capital to take advantage of process innovation would continue to be an important factor in the future.

TABLE 1

Value of Shipments (in millions of dollars)

Year	3471	3479	Total Metal Finishing
1992	4,792	5,240	10,032
1991	4,124	4,634	8,758
1990	4,513	4,929	9,442
1989	4,452	4,756	9,208
1988	4,324	4,867	9,191

(Source: 1992 Annual Survey of Manufacturers Preliminary Industry Reports U.S. Department of Commerce)

TABLE 2

Finisher Market Segments, 1993
Sales Weighted

Automotive	47.9%
Electronics	11.1%
Consumer Durables	7.9%
Job Shops	7.8%
Aerospace	4.6%
Government	4.4%
Machine Tools	3.4%
Recreational Goods	3.1%
Medical	2.2%
Hydraulic Equipment	2.0%
Jewelry/Eyeglasses	0.2%
Other	5.6%

(Source: Surface Finishing Market Research Board)

TABLE 3

Number of U.S. Metal Finishing Facilities

	3471			3479		
	Companies	Facilities	Facilities with < 20 employees	Companies	Facilities	Facilities with < 20 employees
1992	3,165	3,300	71.1%	1,812	1,936	67.0%
1987	3,353	3,451	69.8%	1,702	1,814	66.0%
1982	3,367	3,450	74.0%	1,524	1,620	68.7%

(Source: 1992 Annual Survey of Manufacturers Preliminary Industry Reports, U.S. Department of Commerce)

TABLE 4

Size of U.S. Metal Finishing Facilities (by employees) -- 1987

Number of employees	3471 facilities	3479 facilities
1-4	943	500
5-9	706	332
10-19	759	366
20-49	719	418
50-99	233	132
100-249	80	57
250-499	8	6
500-999	3	3
	3,451	1,814

(Source: 1987 Annual Survey of Manufacturers U.S. Department of Commerce)

TABLE 5

World Exports of Other Manufactured Metal Products (millions of U.S Dollars)**

	1980	1990	1992
United States	3,943	5,477	6,598
Japan	3,590	4,093	4,842
Developing Economies -- Asia	2,400	8,270	10,411

** United Nations classification "Other Manufactured Metal products" includs ISIC codes 691-695, 812 -- fabricated structural components; containers; hardware; wire products; hand and machine tools; and sanitary, plumbing, and heating fixtures

(Source: United Nations Yearbook of Industrial Statistics, 1992)

TABLE 6

1993 Average Profitability Measures

	3471 (468 establishments)	3479 (312 establishments)
Net Sales	$1,142,147	$1,065,166
Net profit after tax	$47,970 (4.2% of sales)	$60,714 (5.7% sales)
Median return on sales	3.4%	4.5%
Median return on assets	5.8%	8.9%

(Source: Dun and Bradstreet, 1993)

TABLE 7

Electroplating Limitations (40 CFR 413)
all values are milligrams per liter (mg/l)

Pollutant (or Pollutant Parameter)	less than 10,000 gallons per day of regulated process flow		more than 10,000 gallons per day of regulated process flow	
	Daily max.	4-day avg.	Daily max.	4-day avg.
Cadmium	1.2	0.7	1.2	0.7
Chromium (total)	NR	NR	7.0	4.0
Copper	NR	NR	4.5	2.7
Cyanide (total)	NR	NR	1.9	1.0
Cyanide-amenable	5.0	2.7	NR	NR
Lead	0.6	0.4	0.6	0.4
Nickel	NR	NR	4.1	2.6
Silver	NR	NR	1.2	0.7
Zinc	NR	NR	1.9	1.0
Total Metals (sum CR, CU, NI, Zn)	NR	NR	10.5	6.8
Total Toxic Organics	4.57	-	2.13	-

TABLE 8

<u>Metal Finishing Pretreatment Standards</u> <u>(40 CFR 433)</u>

Existing Source Limitations
all values are milligrams per liter (mg/l)

Pollutant (or Pollutant Parameter)	Daily Maximum	30-day Average
Cadmium	0.69	0.26
Chromium (total)	2.77	1.71
Copper	3.38	2.07
Cyanide (total)	1.20	0.65
Cyanide-amenable	0.86	0.32
Lead	0.69	0.43
Nickel	3.98	2.38
Silver	0.43	0.24
Zinc	2.61	1.48
Total Toxic Organics	2.13	-

TABLE 9

1992 Estimated Pollution Abatement Operating Costs (Average per facility)

	3471 -- Plating and Related (sample of 951 facilities with 20 or more employees)	
	Estimated ave cost	Percent of total env.mgmt.
Labor	$31,230	24.2%
Energy	$11,357	8.8%
Depreciation	$12,092	9.3%
Contracts	$17,876	13.9%
Materials	$37,960	29.4%
Payments to govt*	$18,191	14.1%
TOTALS	$128,706	100%

* Payment to government includes payments to federal, state, or local government units for sewerage or waste collection/disposal. It does not include permit or legal fees, fines, and taxes

(Source: U.S. Department of Commerce Current Industrial Reports -- Pollution Abatement Costs and Expenditures, 1992)

TABLE 10

Environmental Management Operating and Capital Cost Expenditures -- 3471

	Operating Costs	Capital Expenditures
Air	8%	25%
Water	62%	62%
Waste	32%	17%

(Source: U.S. Department of Commerce Current Industrial Reports)

SOURCES

Metal Finishing Industry Market Survey 1992-1993, by Surface Finishing Market Research Board, published by Metal Finishing Suppliers' Association and National Association of Metal Finishers (1994).

Bahner, Mark & Baskir, Jesse, *Summary of Federal Research on Metal Finishing Pollution Prevention,* Center for Environmental Analysis, Research Triangle Institute, NC (May 1995)

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

Darnay, Arsen J., editor, "Plating & Polishing," *Manufacturing, U.S.A., Industry* Analysts Statistics & Leading Companies, 4th edition, volume 2, pp. 1427-1436. Gale Research, Inc., Detroit, MI (1994).

Dini, J.W., "An Electroplater's View of PVD Processing," *Plating and Surface Finishing,* pp. 26-29, January 1993.

Gallerani, Peter, CEF & Drake, David, "Wastewater Management for the Metal Finishing Industry in the 21st Century," *Plating and Surface Finishing,* pp. 28-35, October, 1993.

Greiner, Timothy *Closed -Loop Metal Finishing Processes,* Office of Safe Waste Management, Department of Environmental Management, MA, (April 1990).

Haveman, Mark, *Profile of the Metal Finishing Industry,* report prepared for the Cleveland Advanced Manufacturing Program under contract with the Energy Environment and Manufacturing Project of the Technology Reinvestment Program, submitted by WRITAR, (April, 1995.)

Steward, F.A., Environment & Competitiveness in the Metal Finishing Industry, report prepared for Congress of the United States Office of Technology Assessment, Washington, D.C., submitted by F.A. Steward Consulting, Inc., Wexford, PA (January 28, 1993).

U.S. Department of Commerce, *1991 Annual Survey of Manufactures, Statistics for Industry Groups and Industries,* U.S. Dept. of Commerce/Bureau of the Census, Survey M91(AS)-1, Washington, D.C. (December 1992).

U.S. Department of Commerce, Bureau of the Census, *1991 Annual Survey of* Manufactures - Value of Product Shipments, U.S. Dept. of Commerce report M91(AS)-2, Washington, D.C. (November 1992).

U.S. Department of Commerce, *Current Industrial Reports - Pollution Abatement Costs and Expenditures, 1992,* U.S. Dept. of Commerce - Economics and Statistics Administration/Bureau of the Census Report MA200(92)-1, Washington, D.C. (March 1994).

U.S. Department of Commerce, Economics & Statistics Administration, Bureau of the Census, *1992 Census of Manufactures, Preliminary Report Industry Series,* report MC92-I-34D(P), Washington, D.C. (October 1994).

U.S. Environmental Protection Agency, *Environmental Regulations and Technology, The Electroplating Industry*, report EPA/625/10-85/001, Washington, D.C. (September 1985).