

Lesson 1**Introduction to the Surface
Finishing Industry**

**By: Frank Altmayer, CEF
Technical Director, AESF**

Slide 1

This is lesson 1 of the AESF-sponsored Introduction to Electroplating and Surface Finishing course.

"Surface finishing" is a generic term applied to a variety of processes for the purpose of enhancing one or more properties of the surface of a metal. It is also applied to a number of processes that involve the application of a metallic coating to a non-metallic surface such as plastic, ceramic, epoxy, and even baby shoes.

Metal Finishing Time Line

<1800	1800	1850	1917-1945	1969	1972	1977
	Galvanic		Anodizing	Electro-paint	Water	
	Cell		Conv.Coating	Electroless Plating	Pollution	
Polishing		Silver	Chromium Plating	Electropolishing	Control	
Grinding		Gold	Bronze Alloy	Vacuum Metallizing	Act	Clean
Painting		Copper	Nickel Plating	Mechanical Plating		Water
Heat Treat		Brass	Chemical Milling	Electrostatic Painting		Act
Tempering		Plating	Phosphating	Electrolytic Paint		
			Others	Powder Coating		

Slide 2

The art of creating an altered surface on a metallic substrate dates back several centuries. Methods of surface finishing such as polishing, grinding, and painting were performed in the same era, along with non-surface finishing processes such as heat treating and tempering of metals.

The modern surface finishing era, however, began with the invention of the galvanic cell in the early 1800s. By the middle of the 19th century, silver, gold, copper, and brass plating were commercially performed. In addition to electroplating, numerous competitive methods of altering the surface of metals and non-conductors have been added to the common definition of surface finishing since the 19th century.

Early surface finishing processes were focused on decorative endeavors, such as jewelry and decorative items, such as lamps and hardware. Some massive parts were manufactured utilizing an electroplating method called "electro-forming," including the street lamp standards for the streets of Paris.

The surface finishing industry received a big boost from the advent of the Industrial Age, and the development of electricity generators in the late 1800s. Metal machine components, hardware, and automotive parts required protection from corrosion-enhanced wear properties, and enhanced appearance.

World Wars I and II and the aircraft industry further developed and refined the industry by adding such processes as anodizing, conversion coating, chromium plating, bronze alloy plating, nickel plating, chemical milling and phosphating, along with numerous other plating processes. Plating equipment evolved from manually operated wooden process tanks to automated equipment, capable of processing thousands of pounds per hour of parts.

The modern era of surface finishing arrived following World War II. Processes such as electro-painting, electroless plating, electropolishing, vacuum metallizing, mechanical plating, electrostatic painting, electrolytic painting (E-coat), and powder coating were commercialized in the last 50 years.

Until 1972, the surface finishing industry was environmentally unregulated (except for selected areas such as Chicago, where a local ordinance by the Metropolitan Sanitary District was passed in 1969) and discharges of concentrated chemicals from finishing processes to sewer systems and surface waters was common. In 1972, Congress gave the Environmental Protection Agency (USEPA) the authority to create regulations for industrial dischargers to the surface waters of the USA, under the Water Pollution Control Act (Public Law 92-500). In 1977, Congress gave EPA additional powers to regulate discharges to sewers under the Clean Water Act (Public Law 95-217). Under this mandate from Congress, EPA developed a system of "categorizing" all industries that discharged pollutants to the surface waters and sewers of the USA. EPA then passed regulations limiting the concentrations and amounts of pollutants that could be in the discharges of process water from those categorical industries. EPA also studied and provided technical information on what technologies could be employed to comply with its regulations.

Clean Water Act

- Pretreatment systems for removal prior to discharge

Clean Air Act

- Control of hazardous air pollutants

RCRA

- Treat and dispose of wastes in environmentally sound manner

CERCLA/SARA

- Cautious waste disposal, where & whom

EPCRA

- Review and reduce hazardous chemicals

OSHA

- Protect workers from chemical exposures

Slide 3

Because of the Clean Water Act, metal finishing facilities have installed and operate pretreatment systems for the removal of heavy metals and other toxins such as cyanide, prior to discharge. Because these pretreatment systems are sized and priced based on flow rates, the industry employs water conservation and recycle/recovery methods.

The Clean Air Act required the surface finishing industry to remove certain air pollutants from its exhaust to the atmosphere.

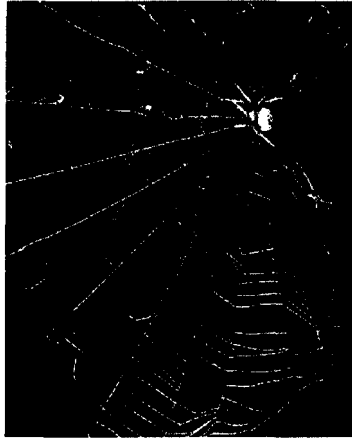
The Resource Conservation and Recovery Act (RCRA) required the industry to treat and dispose of wastes generated from surface finishing operations and pretreatment systems in an environmentally sound manner. The industry responded by developing alternate processes that generated less waste or waste that was less toxic or non-hazardous.

Comprehensive Environmental Response, Compensation & Liability Act 1980/Superfund Amendments and Reauthorization Act (CERCLA/SARA) caused companies in the industry to become much more cautious about where and whom to send their wastes for disposal.

Emergency Planning & Community Right-to-Know Act (EPCRA) caused the members of the finishing industry to review and reduce the quantities of hazardous chemicals on hand at any given time, reducing potential danger to their neighbors.

The Occupational Safety and Health Administration (OSHA) regulations have caused companies in the industry to change to less toxic processes and to ventilate their processes in order to protect their workers from chemical exposures.

Today, there are between 6,000 and 12,000 captive and jobshop finishing facilities. Jobshops are considered to be a "service" industry; they take parts manufactured by others, apply a metal finishing process or processes to those parts, and then return them to their clients. The average facility processes approximately 2 million square feet of parts per year (source: MFSA/ NAMF survey). Total industry employment is approximately 500,000 people with an annual contribution to gross domestic product of 23.6 billion dollars. Sixty-eight percent of all plating is performed on ferrous substrates, 14 percent on copper/alloys, 9 percent on aluminum, 6 percent on plastic, and the balance on zinc die castings (probably a low estimate).



Electroplating

- **Most common finishing process**
- **DC current plus metal ions**
- **Inexpensive**
- **Easy**
- **Safe**
- **Conductive surfaces and Non-conductors can be plated**

Slide 4

Electroplating is the most common metal finishing process. It utilizes a combination of a chemical solution formulated to contain metal ions or complexed metal ions plus a DC electric current to convert the metal ions in solution to solid metal atoms on the surface of the substrate that the DC current is applied to. Electroplating offers the advantages of being inexpensive: It requires relatively inexpensive equipment, is comparatively easy and safe to do, and is easy to do in bulk quantity. Plated metal coatings can be used for a variety of purposes, including corrosion resistance, appearance, solderability, electrical resistance, electrical conductivity, vibratory bonding, abrasion resistance, electroforming of a product, and as a matrix to hold abrasives such as diamonds and carbides in cutting tools. The widest variety of metal surface properties can be obtained through electroplating processes.

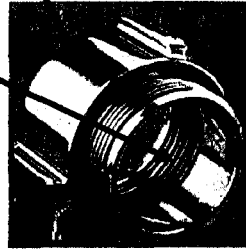
Any surface (with proper preparation procedures) can be electroplated, even a spider in her web!

More details of the electroplating process will be provided later in this lecture.

Electroless Plating

Thickness on Threads = Thickness on Body

- More expensive
- More uniform coating
- Plating on non-conductors
- Control magnetism
- Hard, wear resistant coatings
- Wire bonding in electronics industry
- Printed wiring boards



Slide 5

Electroless plating utilizes a chemical solution containing metallic ions, but no DC current is applied. The "electrons" required for reducing metal ions to metal atoms are instead supplied by another chemical ingredient, called a "reducing agent." Electroless plating is very expensive, more dangerous to perform, and difficult to do in bulk quantity. Equipment costs are similar. Electroless plating offers the advantage of providing very uniform coverage over complex shapes, while electroplating can not cover complex shapes uniformly, without use of labor-consuming shields and auxiliary anodes. Electroless plating processes can also provide coatings with unique properties such as magnetism, corrosion resistance and abrasion resistance. Electroless plating processes are commonly employed in the manufacture of electronic components, especially parts requiring wire bonding, and in the manufacture of printed circuit boards (properly termed "printed wiring boards").

Conversion Coatings

- Anodizing:
- Applied to Al and Mg
- Chemical solution (no metal ions)
- DC current (+)
- Converts surface to an oxide,
- Metal is partially dissolved



Anodized/Dyed
Aluminum Test Coupons

Slide 6

Anodizing is a process most commonly performed on aluminum and magnesium. The process utilizes a chemical solution and DC current to convert the surface of the metal parts to an oxide, commonly called an *anodized coating*. Anodizing differs from electroplating, in that the process solution is designed to generate oxygen gas which forms the coating by reaction with the basis metal ions, as the basis metal dissolves. Anodizing solutions may contain metal ions such as chromates (in chromic acid anodizing), aluminum (from dissolution of base metal), and other metallic impurities. Anodic coatings are not **applied** to the surface. The surface is actually simultaneously converted to the oxide and dissolved by the chemical solution, creating billions of tiny pores in the coating. The pores allow the coating to be colorized, using dyes and other specialized techniques. During anodizing, the aluminum or magnesium parts have a positive (+) DC charge applied, while in electroplating, the parts are negatively (-) charged.

Conversion Coatings

Phosphating:

Converts surface into crystalline phosphate coating

3 Categories:

- **Iron-spray, prior to painting**
- **Zinc-steel, prior to oil or paint**
- **Manganese-thick, abrasion resistant**

Slide 7

Phosphating is another "conversion" process that utilizes an acidic solution containing phosphoric acid and other ingredients to convert the surface of the steel parts into crystalline phosphate coatings. There are three major categories of phosphates: iron, zinc, and manganese. Iron phosphates are most commonly applied in spray operations prior to painting, in equipment typically termed a phosphating line. Zinc phosphate can also be applied prior to painting, but is commonly applied to steel parts (especially fasteners such as machine screws and bolts) prior to application of a corrosion-inhibiting oil. The phosphate crystals act as a holding mesh for the oil. Manganese phosphates are very thick, abrasion-resistant coatings applied to specialized parts in the aerospace industry and on hardware subjected to an abrasive environment.

Other Conversion Coatings

Black Oxide

- Sodium hydroxide, high temp.

Chromating

- Chromates & other chemicals, thin film

Coloring

- Chemicals convert surface to desired color

Slide 8

Conversion coating is a generic term for any process that converts the surface of a part to a coating. We have just covered two conversion coatings that are somewhat specialized (anodizing and phosphating), but there are numerous other types of conversion coatings:

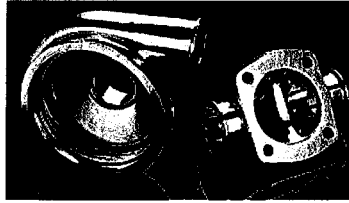
Black oxide: An immersion process in which metal parts are immersed in a molten solution of sodium hydroxide at high temperature (275 °F) to form a black iron oxide.

Chromating: An immersion process in which metal parts are immersed in a solution containing chromates and other chemicals for the purpose of converting the surface to a thin film that enhances the corrosion resistance and paint adhesion of the surface.

Coloring: An immersion process that utilizes chemicals to convert the surface of a metal part to a coating that has a desired color. This process is commonly employed by decorative lamp, furniture and hardware manufacturers

Burnishing

Water solution with abrasive, vibrated/tumbled



Electropolishing

Chemical solution & DC current, mirror smooth surface

Chemical Milling/Etching

Chemical solution dissolves unmasked area

Slide 9

Burnishing is a process that utilizes a water solution of soaps and other ingredients along with abrasive media to remove sharp edges and metal slivers from stampings and machined/ drilled parts. The parts are vibrated or tumbled with this mixture until the desired finish is obtained.

Electropolishing utilizes chemical solutions and DC current to dissolve off a thin film of metal from a surface in such manner that more metal is removed from the peaks of rough surfaces than from the valleys. The resulting surface can be mirror smooth. For appearance purposes and because an electropolished surface inhibits bacterial growth, the process is most commonly applied to stainless steel components, especially in the food service and medical industries,

Chemical Milling/Etching are processes commonly employed in the aerospace industry and in the manufacture of printed wiring boards. The metal parts are masked with a chemical resistive coating at areas that are not to be etched/milled, and are then immersed in a chemical solution that dissolves the unmasked area at a uniform rate, until the desired amount of metal is removed.

Electropainting

- DC current and specialized paint

Vacuum Metallizing

- Vaporized metal ions, vacuum chamber

Mechanical Plating

- Tumbling of solution, metallic powder & glass beads

Slide 10

Electropainting utilizes DC current and a specialized paint that becomes adherent to immersed metal parts, when the current is applied. The combination of current and paint allows for more uniform and complete coating of complex-shaped parts. The process is commonly performed by the automotive industry on car body panels and on hardware.

Vacuum metallizing is a process that utilizes vaporized metal ions in a vacuum chamber that "condense" onto the parts held within the chamber and "metallize" the parts (along with everything else inside the chamber). The process is commonly employed to apply thin metallic films on plastic parts, such as toys. Variations of the process are also currently in use to apply thick coatings of aluminum, cadmium, titanium nitride and numerous other coatings on industrial parts, inexpensive jewelry, and aircraft components. The process is almost pollution-free, but the equipment is very expensive and limited in productivity.

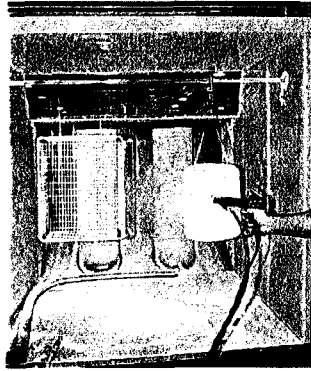
Mechanical plating utilizes water-based solutions containing various patented ingredients, plus metallic powder and glass beads. The solution and parts to be coated are tumbled in large rotary tumblers. As the beads and parts impact with each other, the metallic powder is "hammered" into the surface of the parts, creating a coating of the metal powder. The process avoids the use of more hazardous chemicals as in electroplating and does not cause hydrogen embrittlement effects on high-strength steel, but is limited in appearance and the types/ combinations of coatings that can be applied.

Spray Painting

Solvent or water-based, possible charge

Powder Coating

High temperature, eliminates solvents



**Small Powder Coating
Spray Booth**

Slide 11

Spray painting is applied to numerous consumer products by utilizing a painting line that may include a phosphating operation prior to painting. The parts are sprayed with various paints that may contain solvents or may be water-based. Spray painting may be accomplished with the use of an electrostatic charge applied to the parts in order to attract the paint to recessed areas and created more efficient use of the paint.

Powder coating utilizes specialized powders that melt onto the parts when heated to a high temperature, thereby creating the "painted" coating. Use of powder eliminates the solvents used in conventional spray painting operations and can create very thick, highly corrosion-resistant coatings. Parts must be able to withstand the high temperatures of the baking of the powder (325 °F or more), however.

Typical Properties Achieved Through Electroplating

- Corrosion Resistance
- Appearance
- Abrasion Resistance
- Value (e.g., Silver/Gold Plate)
- Solderability
- Rubber Bonding
- Electroforming
- Electrical Resistance
- Reflectivity
- Diffusion Barrier
- Lubricity
- High Temp. Resistance

Slide 12

Choosing the Right Plating Coating

The choice of what metal(s) are to be plated on a part is usually made by the design engineer at the manufacturing site. Plated and chemically applied coatings are typically selected to enhance one or more of the properties shown.

The designer will usually find that there is not much choice as to which combination of coatings is the best for his/her application. The plating combination that will provide the best compromise of cost vs the above benefits will usually be that specified for the part. The designer will then create a "specification" for the part that will detail the type of plating, the thickness range that each plated layer is to have, special properties (hardness, solderability etc.) that the plating is to have, and the subsequent coatings, if any, that are to be applied after plating.

The following are typically plated metals and alloys and the possible reasons for specifying them:

<u>Plated Metal</u>	<u>Beneficial Property</u>	<u>Common Uses</u>
Zinc	Inexpensive corrosion protection	Hardware, fasteners, automotive
Zinc-alloy	Superior corrosion protection	Cadmium Substitute
Cadmium	Corrosion protection, lubricity, solderability anti-fouling	Electronics, hardware, fasteners, aerospace, weapons, automotive

Slide 13

<u>Plated Metal</u>	<u>Beneficial Property</u>	<u>Common Uses</u>
Copper	Ductile underlayer decorative, conductivity, diffusion barrier	Electrical cable, pennies, die castings, electronics, carburizing, electroforming, automotive, plated plastic, circuit boards
Brass	Decorative, promotes adhesion of rubber to steel	Furniture, hardware, vulcanizing, consumer items
Bronze	Decorative, lubricity	Consumer goods, bearings

Slide 14

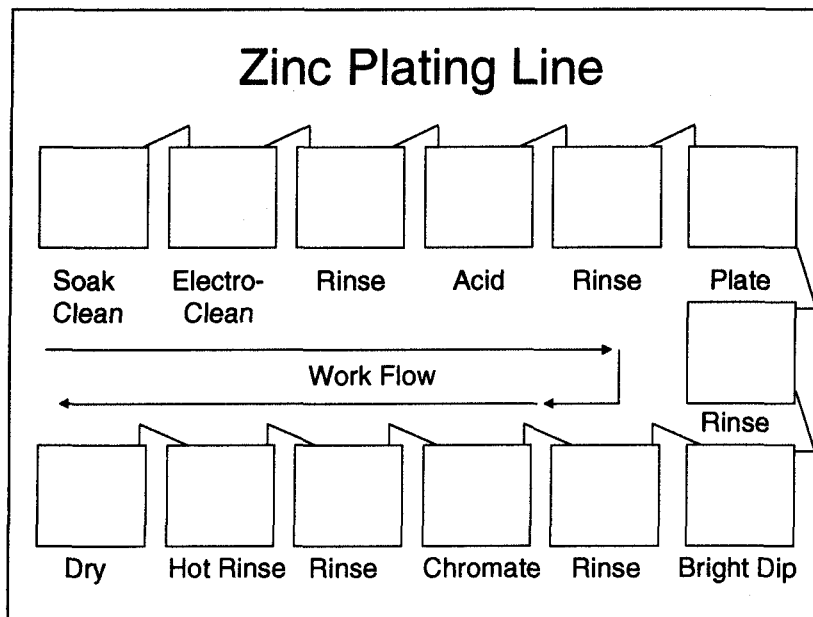
<u>Plated Metal</u>	<u>Beneficial Property</u>	<u>Common Uses</u>
Nickel	Decorative, wear resistant anti-tarnishing, corrosion resistant,	Consumer goods, electroforming, electronics, tools automotive, plated plastics, circuit board mfg.,
Chromium	Wear resistant, anti tarnish, decorative	Consumer goods, aerospace, automotive, heavy equipment
Gold	Decorative, low contact resistance, anti-tarnish	Electronics, jewelry circuit board mfg. automotive, aerospace

Slide 15

<u>Plated Metal</u>	<u>Beneficial Property</u>	<u>Common Uses</u>
Silver	Electrical conductivity appearance, solderability	Electronics, jewelry home furnishings,
Tin	Corrosion resistant, solderability, ductility, non-toxic	Steel stock for cans, electronics, circuit board mfg., food utensils
Tin-lead	Solderability, corrosion resistance	Electronics, circuit board mfg.

Slide 16

There are numerous other metals and alloys that can be plated to obtain specific benefits. These include precious metals other than gold and silver (rhodium, palladium, ruthenium, platinum), and some uncommon "common" metals and alloys such as bismuth, iron, alballoy (copper-tin-zinc). There are also "composite coatings" that can be plated. For example, one can plate a nickel-cobalt alloy containing finely dispersed particles of silicon carbide to enhance abrasion resistance. This, or a some other composite may one day be a substitute for chromium plating.



Slide 17

Plating Line/Department Except for vapor degreasing, which normally is performed off-line, plating operations are normally incorporated into a sequence of tanks, called a "line."

A plating line may be designed to produce a single coating or a number of coatings. While not always the case, the process line contains tanks lined up in sequential order. Automated lines may or may not contain tanks in sequential order.

A zinc plating line may therefore consist of 13 tanks, each containing a chemical processing solution or rinse water, soak clean, electroclean, rinse, acid, rinse, zinc plate, rinse, bright dip, rinse, chromate, rinse, hot water rinse, and dry. If the line is for barrel plating, each tank may have one or more "stations," that is, places to put a barrel. A six-station zinc plating tank can plate six barrel-loads of parts at one time. To economize, some shops may have one cleaning line that services several plating lines. There also are tanks for rack stripping, stripping rejects, purifying contaminated solutions or holding solutions that are only sporadically used. The entire lineup of tanks and lines creates a "layout" of the shop, with parts entering the plating department from one direction, traveling through the process lines, and leaving the plating department.

Electroplating Equipment


1. **Rack or barrel to hold parts and make electrical connection**
2. **Tank to contain plating solution and accessories**
3. **A power supply such as a DC generator, battery or rectifier**
4. **Filtration equipment (optional in some plating processes)**
5. **Agitation equipment (optional in some plating processes)**
6. **Ventilation equipment (may be optional)**
7. **Plating solution**
8. **Other processing tanks for cleaning, rinsing, acid pickling and waste treatment**

Slide 18

The Electroplating Process Electroplating is a process for coating a metallic or non-metallic substrate with a metallic coating through the use of a combination of electricity and a chemical solution that includes the ions of the metal in the coating. To conduct the process, we first need to purchase some hardware. Simple electroplating hardware consists of the items in the above slide.

Methods of Plating

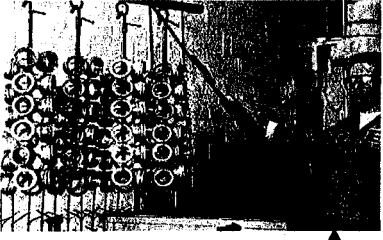
Plating can be performed using three main methods of part handling, each requiring different hardware:




Rack Plating

AKA: Still Plating
More Expensive Than Barrel Plating
Rack Stripping & Maintenance Required

Automation:
Better Product Uniformity
Lower Labor Costs
Less Waste
Higher Production



↑
Manual

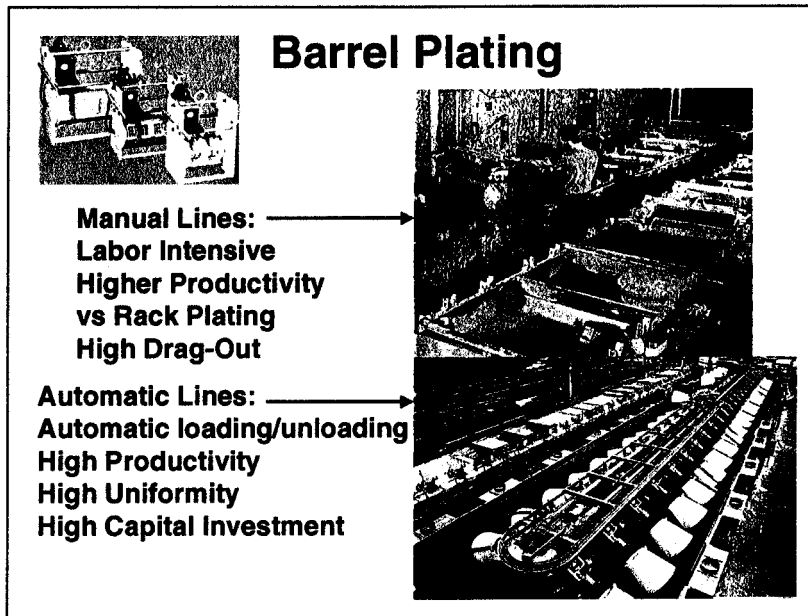


← Automatic

Slide 19

Rack plating is sometimes referred to as *still plating* and is used whenever the parts are too large, delicate or complicated to be barrel-plated. Rack plating is much more expensive than barrel plating because of the labor involved in putting the parts on the rack and taking them off after they are processed. Rack plating is performed by hanging the parts to be plated on "racks," which are typically plastic-coated copper or aluminum rods, with stiff wires/hooks that protrude at various intervals, hold the parts in place, and make electrical contact. Racks come in numerous designs and are most often constructed by outside vendors and sold to the metal finisher. Some small parts are "racked" simply by twisting a thin copper wire around them. The wire, with perhaps 20-50 pieces hanging on it, is then handled as a "rack." During plating, the part of the rack that makes electrical contact with the part being plated is also plated. After several cycles, these contacts have a lot of metal buildup. The racks are then sent through a stripping solution that removes the excess metal, or the plater physically removes the excess metal using pliers or a hammer. Chemical rack strippers are usually strong solutions of cyanide or acid and can be difficult to waste-treat. Non-cyanide and regenerative strippers are available for some processes, but are expensive to use or they may strip very slowly.

Rack plating lines can be automated, using programmable hoists and process controllers. Automated lines yield better product uniformity, provide higher production rates, and generate less waste as a result of the ability to program and reproduce adequate processing, draining, and rinsing times for the racks.



Slide 20

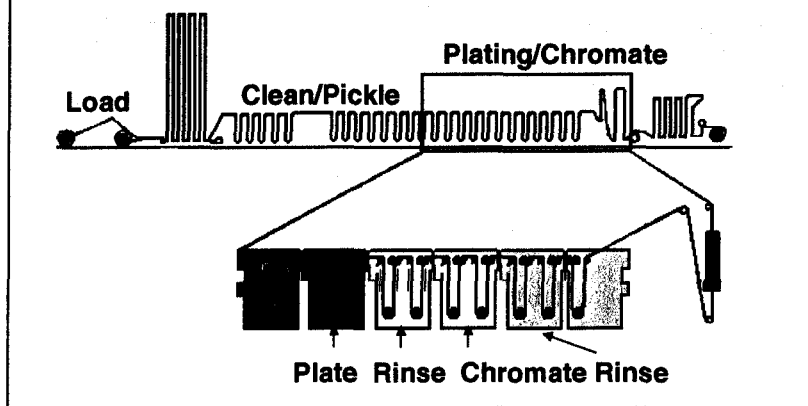
Barrel plating is the most efficient and least costly method. Plating barrels of varied designs are purchased from manufacturers of such products. The basic barrel consists of a hexagonal cylinder, closed at both ends, with perforated walls made of polypropylene. A "door" that is held in place with plastic-coated clips is installed in one wall of the barrel to allow entry and exit of the load. Electrical contact between the saddle on the tank and the parts inside the barrel is made by a copper or bronze rod attached to the barrel that sits in the electrified saddle. The rod has a cable attached, and this cable is routed inside the plating barrel through the end of the barrel. Sometimes two cables are used, one entering each end of the barrel. The barrel has a hole in the center that allows for the cable to enter. The end of the cable, inside the barrel, has a stainless steel ball attached, called a "dangler." This dangler makes contact with the parts inside the barrel by gravity. There are other methods of making electrical contact inside the barrel, including rods and button contacts, but the dangler is the most commonly used method. Parts to be plated are scooped or shoveled into the barrel. The load is often weighed to make certain that the parts are uniformly plated. As a general rule, the barrel is never filled beyond 1/3-1/2 the total volume inside. As plating proceeds, a motor mounted either on the plating tank or on the barrel turns the barrel at 3-5 rpm, through either a drive belt or a set of gears mounted on the barrel. If the barrel was not rotated during plating, the top of the load would be plated and the parts in the bottom would remain bare.

Barrel plating can be performed on a manually operated plating line as illustrated above. The barrel is loaded and transferred from one process tank to the next by a worker using an electric hoist. The worker must take great care to keep the barrel in each process tank for only the required amount of time, so that each work load matches another in quality. Workers must also make certain that each barrel is drained as completely as possible after each process to reduce waste. The plating line should be designed to prevent the process solution from dripping or draining to the plant floor. For economy, most barrel plating lines utilize lined and unlined steel tanks, which are likely to corrode from the outside (as seen in the photo). If not properly maintained, this leads to tank perforation and costly process solution loss.

Automated Barrel Plating

The barrel plating operation can be automated by the addition of a programmable hoist to move the barrels and keep track of process times. The newest facilities also incorporate process controllers and even analyzers to automate the process operating conditions and solution chemistries. The programmable hoist line utilizes horizontally oriented barrels that are difficult to automate for loading/unloading. The oblique barrel plating machine shown above, allows for automated loading/unloading because the top of the plating barrel is open. The machine unloads by tilting the barrel upside-down. The oblique plating machine utilizes a return-type conveyor to move the barrel from one station to the next. The barrel is lifted over the tank walls during transfer. In both types of plating machines, the plating thickness obtained is determined by the residence time in the plating tank. In the case of the oblique plater, residence is determined by the size of the plating tank, because the barrel must stay in the tank while the machine indexes (moves the barrel from one place to the next). For this reason, oblique plating machines have very large capacity plating tanks (some machines have 10,000-gallon plating tanks). This results in high operating costs. The barrel in a horizontal plating machine stays in place, reducing solution volume and operating costs. The oblique plater, however, has the advantage of higher productivity.

Continuous Strip Plating Schematic

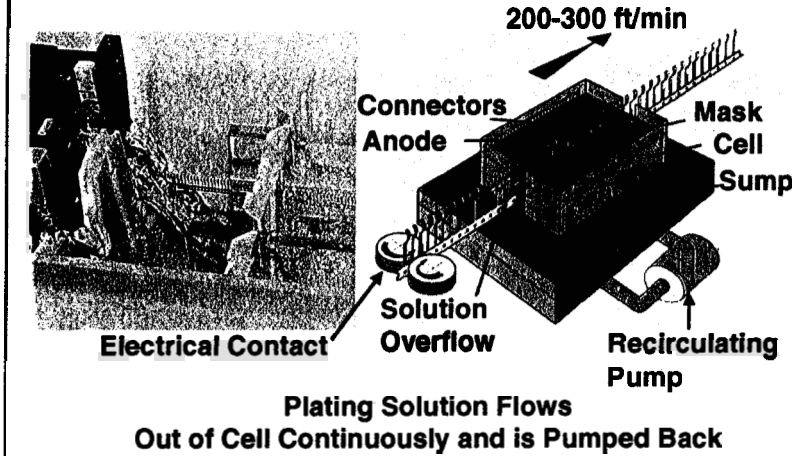


Slide 21

Strip Plating is a method of plating is highly efficient and competes effectively against all other methods, when the parts are small, uniform, of simple geometry, and amenable to being stamped from a thin strip of metal, or when parts are small and must be "selectively" plated (plated only in specific areas). This method is used to electrogalvanize (zinc-plate) steel strip that is used to stamp automobile bodies and to plate brass or copper strip for stamping electrical connectors for telecommunications. In this method of plating, the parts to be plated consist of long strips of metal rolled up into a coil. The coil is mounted on the equipment and the strip goes through a sequence of rollers that direct it through various processing tanks, including the plating tank. The metal strip may partially dip into the plating tank, or be completely immersed. The strip may also travel through the plating line in vertical or horizontal orientation. Electrical contact is made either through metal brushes, rollers, or by a principle called "bipolarity" (electromagnetically induced polarity), which does not actually contact the strip. The strip may travel at speeds ranging from 50 to 1000 or more feet per minute. The strip travels through the same process sequence as for regular plating (clean, rinse, acid, rinse etc.). At the other end of the continuous strip plating line, a second wheel takes up the processed strip. Continuous strip plating equipment is typically automated, except for process chemistry, and is very expensive to purchase, install and operate. The process must be very carefully monitored, or a large amount of waste (reject) material is produced in a very short period of time. This is especially important for continuous plating of precious metals, such as gold or silver.

Continuous/Reel to Reel Plating

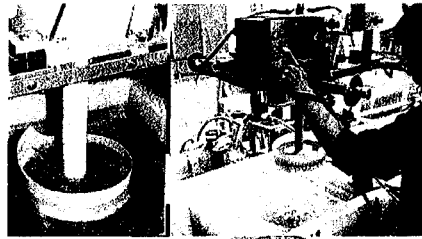
Strip May Be 100's of Feet Long



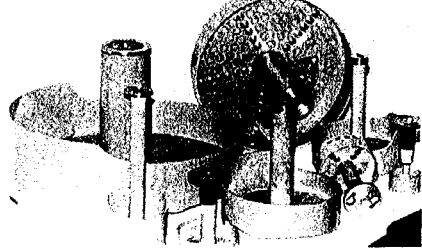
Slide 22

Reel-to-Reel Plating is a method of plating is similar in principle to strip plating, but is usually done on a much smaller scale. The tanks for reel-to-reel plating may only hold a gallon or a few gallons of plating solution. Below the plating cell is a sump tank that holds much more plating solution than the plating cell. The plating solution in the plating cell is continuously replenished via a recirculating pump. Reel-to-reel plating is commonly performed on electrical contacts for the telephone and computer industry. It is a far more efficient way to plate delicate parts than barrel plating.

Vibratory Plating

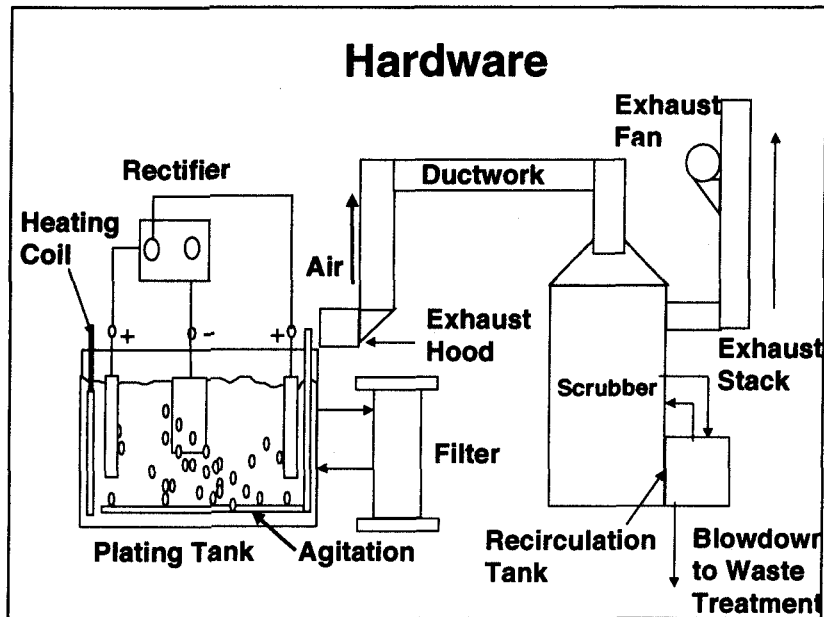


- Delicate Parts
- Uniform Deposition
- Higher Plating Speed vs Barrel Plating
- Higher Cost vs Barrel



Slide 23

Vibratory plating utilizes a vibrating basket to plate delicate parts such as electronic interconnect components, and costume jewelry. Fragile parts can be plated without tumbling (barrel plating), which can abrade or disfigure such surfaces. In vibratory plating, a vibration generator transmits pulses down a vertical shaft to a basket containing the parts to be plated. The basket and parts are immersed into the plating solution. The vibration generator causes the parts to move around the basket's axis in a gentle manner, while the parts are plated. Electrical contact is provided by metal button contacts built into the bottom of the basket. The process typically yields more consistent deposit appearance, better throwing power than most barrel plating (but less than reel-to-reel plating), faster plating times (vs. barrel plating), and reduced drag-out. Disadvantages include high cost for the equipment and limited application (delicate, small parts).



Slide 24

The hardware required to perform plating is typically purchased from a company that specializes in producing this equipment, although some platers produce their own hardware. Let's take a closer look at the hardware used for plating:

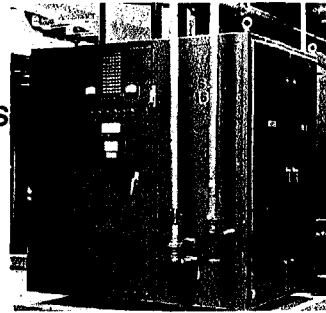
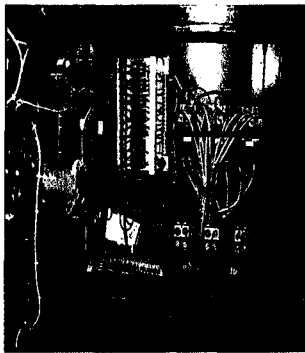
1. Tank

The plating tank must resist chemical attack from the plating solution. Tanks containing cyanide plating solutions are often made of bare steel. Tanks for other plating solutions are typically made of steel with PVC lining, polypropylene, polyvinyl chloride or polyethylene. Plating tanks should not have any wall perforations below the liquid line, to prevent accidental discharge of contents. Whenever possible, a tank should be made from noncorrodible materials such as polypropylene, polyethylene, Kynar, PVC or fiberglass. If the tank must be metal, it should be made from stainless steel or lined stainless steel. A "rack" plating tank typically has three copper bus bars mounted on top of the tank. One bus bar is in the center and is used to hang the parts in the plating solution. The other two bus bars are located near the walls of the tank, and are used to hang anodes or "baskets" for anodes. A barrel plating tank has the same anode bus, but there is no center bus. Instead, the tank typically has four "saddles" made of copper or bronze, mounted to the lips of the tank, so that the barrel contact rods can sit firmly in the saddles. At least one of the four saddles has a cable, or copper bus attached to it for contact with the rectifier.

Rectifiers

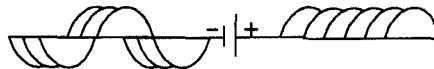
Air Cooled

Water Cooled



Diodes

AC



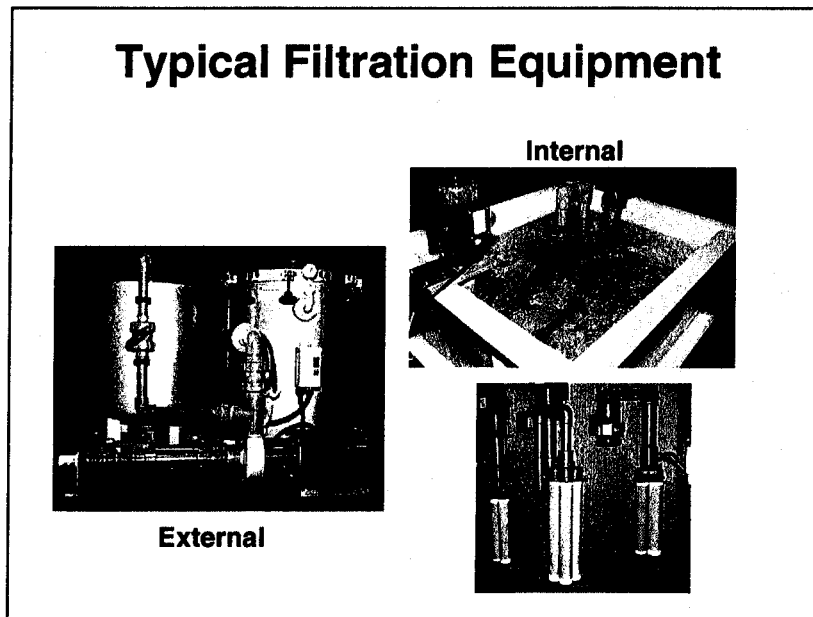
DC

Slide 25

2. Rectifier

The rectifier for plating converts the AC current to DC. The rectifier is typically installed near the plating tank, but may be located in a separate room (in which case a remote control is installed near the tank). In either case, cable or bus bar is used to connect from the positive terminal of the rectifier to the anode bus bar on the tank. The negative terminal of the rectifier is connected by cables or copper bus to the saddle of barrel plating tanks or to the cathode bus of rack tanks. Rectifiers generate heat as a by-product. This heat must be removed by using either a fan (air-cooled) or by circulating cooling water through the rectifier (water-cooled). The water used to cool the rectifiers can be routed to other plating or processing operations, such as rinsing.

Typical Filtration Equipment

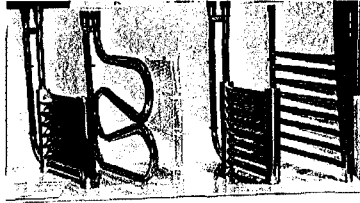


Slide 26

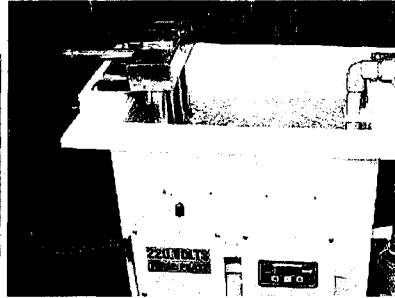
3. Filter

Some plating solutions require continuous filtration, while others do not. A general rule is that alkaline solutions can usually operate satisfactorily without a filter, while acidic solutions need filtration to avoid particulates suspended in the solution from being incorporated into the coating, yielding "roughness." Use of filters, even on tanks where it is not mandatory, almost always reduces rejects. While the filter shown in the slide is located outside the tank, it is recommended practice to locate the filter inside the tank whenever possible. If located outside, a containment dike or containment tank should be used, because process solution is usually spilled during servicing of the filter (replacement of filter elements or media). Newer filters utilize re-usable media to avoid the need for disposing of spent filtration materials.

Methods of Heating Solutions



Steam/Hot Water

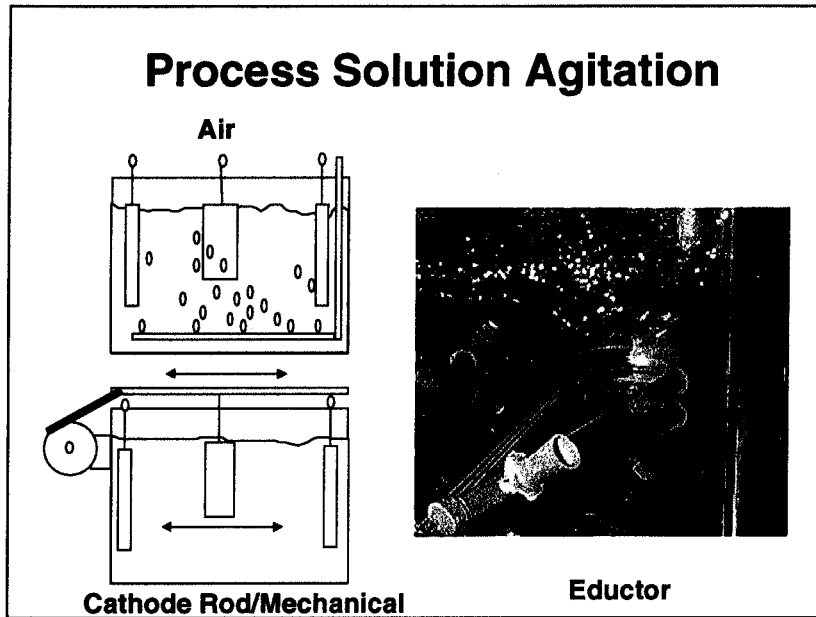


Electric Heaters

Slide 27

4. Heating Equipment

Many plating processes need to be operated at elevated temperatures, for the process to deliver the best-performing deposit. Raising the temperature of the process can be performed by inserting a heating coil into the process solution and introducing steam into the coil. The most common alternate method of heating the process solution is to use electric immersion heaters.

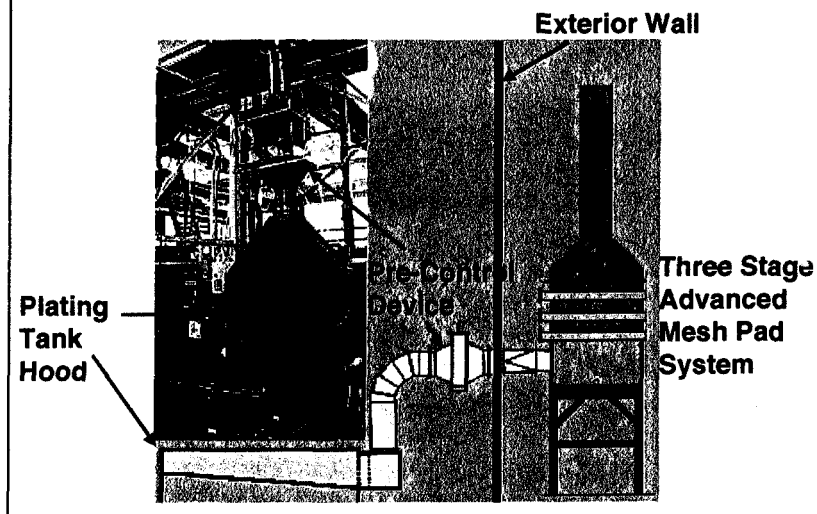


Slide 28

5. Agitation

Most plating processes require some form of solution agitation to deliver the brightest, densest, most uniform deposit, and to plate at higher current densities without "burning." A common method of agitation is to move the cathode rod back and forth in the solution, using a motor attached to the cathode rod. This is called *cathode rod agitation*. A second common method is to install an air sparger in the bottom of the plating tank and use low pressure air bubbles to perform the agitation. A less common technique is to use a prop mixer. Plating tanks for barrel plating are not agitated because the rotation of the barrel provides sufficient solution movement.

Ventilation of Process Tanks



Slide 29

6. Ventilation System

Process solutions that emit mists or fumes during use require a ventilation system to capture the offending emissions and vent them outside the process building (for worker safety and to protect equipment from excessive corrosion). If the emissions contain air pollutants that must be controlled, the ventilation system will include a scrubber or demisting system. Scrubbers and demisting systems use water sprays, and therefore generate a contaminated wastewater that must either be recycled back to the process or waste-treated. Clean Air Act regulations on certain emissions require the installation of additional equipment for removal of pollutants from ventilation systems.

Typical Processes Requiring Ventilation

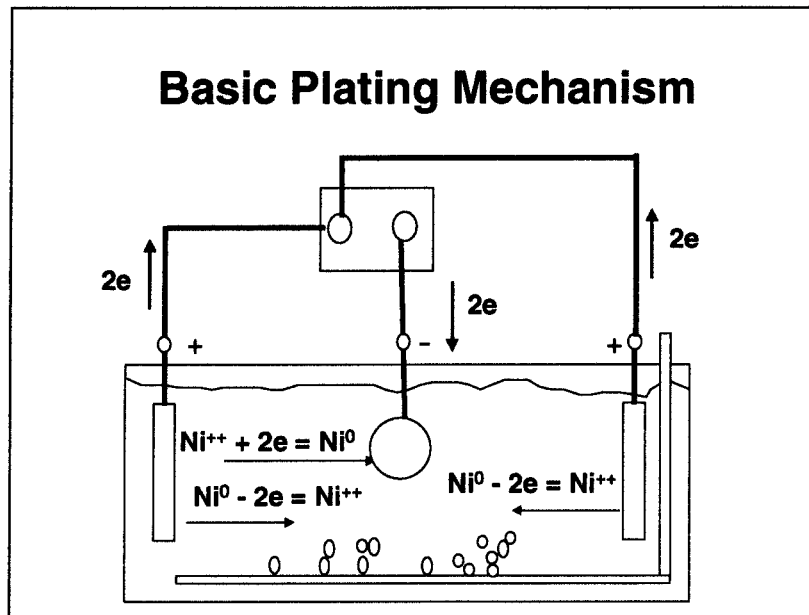
	Ventilation	Scrubbing/Demisting
Chromium Plating	X	X
Nickel Plating (air agit.)	X	
Wood's Nickel	X	X
Hydrochloric Acid	X	X
Nitric Acid	X	X
Hot Cleaners	X	
Electrocleaners	X	X
Electroless Nickel	X	

Slide 30

Plating and processing solutions that typically require ventilation systems and scrubbing equipment are shown in this slide. The slide covers only a partial list of such processes. Additional information on ventilation requirements and design can be found in the OSHA regulations 29 CFR, section 1910.94 and in Electroplating and Engineering Handbook, (available from AESF).

Ventilation and scrubbing may be regulated on a federal, state, and local basis. A metal finisher is required to meet all of these requirements.

Basic Plating Mechanism



Slide 31

The plating solution normally contains water and a number of ingredients that determine if the coating produced is dense, bright, hard, a certain color, or a number of other desirable properties that can be obtained through chemistry. It also contains an ingredient that, when added to water, forms ions of the metal to be plated. For example, one ingredient in a Watts nickel plating solution is nickel sulfate. When nickel sulfate is added to water, it dissolves and forms nickel ions and sulfate ions (just like when salt is added to water, it dissolves form sodium and chloride ions). The dissolved nickel ions can be converted to nickel metal by passing a direct current through the plating solution using the rectifier (which converts AC current to DC), the anode is the electrode with positive polarity, and the part we want to electroplate is the electrode with negative polarity. The conversion of the nickel ions to nickel metal will occur on the surface of the negative electrode, where excess electrons (which make the electrode negatively charged) "reduce" the nickel from ions to metal. While nickel ions are converted to metal at the cathode (negative electrode), nickel metal at the anode is converted from the metal back to the ions. Ideally, for each nickel atom plated out at the cathode, we will form a new ion at the anode to replace the one plated out. This is the case in most plating solutions, but there are some solutions where the anode is not converted to metal ions. In cyanide-based solutions, metal is plated from metal ions complexed with cyanide. In cyanide zinc plating solution, zinc is plated from two complexes—the metal-cyanide complex, and a complex between the zinc and hydroxide (called a zincate complex). Tin is plated from an alkaline stannate complex in the alkaline tin plating solution. Tin can also be plated from an acid sulfate, fluoborate, or sulfonic acid solution.

Plating Solutions

Metal

Matrix

Zinc	Acid Chloride, Alk. Non Cyanide, Cyanide
Copper	Acid Sulfate, Cyanide, Pyrophosphate, Fluoborate, Alkaline Non-cyanide
Nickel	Sulfate, Chloride, Sulfamate
Chromium	Chromic acid, Chloride, Sulfate
Silver	Cyanide, Proprietary Non-cyanide
Gold	Cyanide, Sulfite
Tin	Alkaline Stannate, Acid sulfate, Fluoborate, Sulfonic acid

Slide 32

Each metal or alloy deposit may be obtained from one of several chemical formulation options. A partial list is shown here, with actual formulations compiled in the appendix. While several types of solutions are indicated, some solutions are favored over others. For example, most silver plating is performed from the cyanide solution, while most zinc is plated from non-cyanide formulations. Tin can be plated from four solutions (see slide), while the sulfate formulation is the most popular.

The choice of solution is made considering factors such as:

- Ease of analysis
- Tolerance for contamination
- Cleaning requirements
- Wastewater treatment complexity
- Economics
- Hardware requirements

Post Plate Processing

- **Drying Operations**
- **Conversion Coating**
- **Passivation**
- **Heat Treatment**
- **Painting/Powder Coat**
- **Application of Sealant**
- **Application of Anti-Tarnish**
- **Application of Dye or Coloring of Deposit**

Slide 33

After plating, parts are often further processed or treated in various chemical solutions to enhance the appearance or corrosion/tarnish resistance of the plated coating. Examples of such operations are shown in the slide.

Parts are most often dried immediately after plating to remove trapped moisture that might yield stains and corrosion.

Chromate films (conversion coatings) applied over zinc, cadmium, and other deposits serve to add additional corrosion protection. Chromate "conversion" coatings are so popular that almost every zinc and cadmium plating line has chromating tanks and rinses built into it. Additional sealants, or colored dyes may be applied over the chromates as well.

Bright nickel plated parts may be immersed in a dilute solution of chromic acid as a passivation dip to enhance corrosion resistance.

Parts may be subject to heat treatment to enhance adhesion, eliminate hydrogen effects, or produce a harder coating.

Powder coating over plated deposits or polished metals can yield finishes that simulate expensive gold plating and other attractive finishes.

Appendix

Typical Plating Solution Chemistries

The following are basic formulations for the most commonly used plating solutions:

1. Zinc

Zinc is the most commonly plated metal, normally applied over ferrous substrates for the purpose of enhancing the corrosion resistance. Zinc can be plated from a number of different chemistries, but the three most common ones are cyanide, alkaline non-cyanide, and acid chloride.

A. Cyanide Zinc

The cyanide solutions are favored when high thicknesses are required or when parts are to be plated and then deformed. Still widely used, cyanide zinc plating solutions contain:

	Cyanide Zinc Solution (g/L)
Zinc cyanide	15-60
Sodium cyanide	8-45
Sodium hydroxide	74-100
Organic brightener	As required
pH	14+
Operating Conditions:	
Temperature	70-90 °F
Anodes	Zinc/steel baskets
Current density	10-50 A/ft ² (1-5 A/dm ²)
Agitation	Cathode rod/non
Filtration	Not required
Color of solution	Straw-colored, (possible floating oily layer)
Odor of solution	Aldehyde
Life	Many years

B. Alkaline Non-cyanide These solutions can be substituted for cyanide solutions without the need for major equipment modifications. The deposits tend to become brittle as the thickness increases and some parts that have been heat treated yield poor adhesion.

Alkaline Non-Cyanide Zinc (g/L)

Zinc oxide	8-15
Sodium hydroxide	75-110
Sodium carbonate	0-22
Additives	As required
pH	14+
Operating Conditions:	
Temperature	70-90 °F
Anodes	Zinc/steel baskets
Current density	5-45 A/ft ²
Agitation	Cathode rod/none
Filtration	Not required
Color of solution	Pale yellow
Odor of solution	Sharp odor
Life	Many Years

C. Acid Chloride

These solutions yield the brightest deposit. The process requires excellent cleaning and corrosion resistant equipment, however, and thick deposits tend to be brittle.

Acid Chloride Zinc (g/L)

Zinc chloride	30-90
Potassium chloride	100-150
Ammonium chloride	22-38
Boric acid	30-38
pH	4.5-6.0
Operating Conditions:	
Temperature	70-115 °F
Anodes	Zinc/titanium baskets
Current density	10-150 A/ft ²
Agitation	Air or cathode rod
Filtration	Required
Color of solution	Pale yellow
Odor of solution	None, sharp with air agitation
Life	Many years

2. Cadmium

The vast majority of cadmium plating is performed from the cyanide based chemistry. The sulfate chemistry has made small in-roads, but often does not adequately cover heat treated steel parts that have high surface hardness. The sulfate process also requires a much higher degree of cleaning.

A. Cyanide Cadmium Solutions

The cyanide based cadmium plating solution contains:

Cyanide Cadmium Solution (g/L)

Cadmium oxide	22-38
Sodium cyanide	75-150
Sodium carbonate	22-100
Sodium hydroxide	15-60
Brighteners/additives	As required
pH	14+

Operating Conditions:

Temperature	70-90
Anodes	Cadmium/steel baskets
Current density	5-90 A/ft ²
Agitation	Cathode rod/none
Filtration	Not required
Color of solution	Pale yellow
Odor of solution	Aldehyde
Life	Many years

Acid sulfate based cadmium plating solution contains:

Acid Cadmium Solution (g/L)

Cadmium chloride	8-10
Ammonium sulfate	75-115
Ammonium chloride	10-22
Brighteners/additives	As required
pH	5-6

Operating Conditions:

Temperature	70-100 °F
Anodes	Cadmium, titanium baskets
Current density	2-15 A/ft ²
Agitation	Cathode rod
Filtration	Required
Color of solution	Pale yellow
Odor of solution	Sharp
Life	Many years

3. Copper

Copper is plated from three popular chemistries, cyanide, acid sulfate, and pyrophosphate. Recently, patented alkaline non-cyanide copper plating processes have been developed and marketed by at least three companies, but they are troublesome and expensive to operate.

A. Cyanide Copper Process There are several cyanide copper plating processes, but they can be divided into two basic chemistries; a strike solution and a "plate" or high speed solution. The ingredients/operating conditions are:

Cyanide Copper Solutions (g/L)

	Strike	Plate
Copper cyanide	10-15	30-60
Sodium cyanide	22-30	60-90
Sodium carbonate	22-100	22-100
Sodium hydroxide	0-10	15-30
Brightener/additives	(none)	As Required
pH	10-10.5	12-14

Note: Potassium salts are most often used in high-speed cyanide copper plating solutions, at approximately the same concentrations.

Operating Conditions:

Temperature	140-160 °F.
Anodes	Oxygen Free High Conductivity (OFHC) copper
Current density	10-100 A/ft ²
Agitation	Cathode Rod
Filtration	Required
Color of solution	Pale Yellow
Odor of solution	Pungent
Life	Strike: Years Plate: Many Years

B. Acid Sulfate Processes

There are two main acid sulfate chemistries used in electroplating copper. One is termed "conventional" and is often used as an underlayer for plated plastic, or in applications where a high degree of "leveling" (smoothing of scratches) is desired. The second process is called a high-throw solution, used mostly by printed wiring board manufacturers because of the ability to produce uniform thicknesses on the outside of a circuit board and on the inside of tiny holes drilled into the board.

Acid Copper Plating Solutions (g/L)

	Conventional	High Throw
Copper sulfate	200-250	75-100
Sulfuric acid	45-90	150-300
Chloride (ppm)	40-80	40-80
Brighteners/additives	yes	yes
pH	<1	<1
Operating Conditions:		
Temperature	Room	
Anodes	Copper containing 0.02-0.06 % phosphorus, bagged	
Current density	20-200 A/ft ²	
Agitation	Air	
Filtration	Continuous	
Color of solution	Deep cobalt blue	
Odor of solution	No specific smell, inhaled mist may yield sharp odor/burning of nose	
Life	Many years	

Pyrophosphate Copper Solutions (g/L)

Copper pyrophosphate	75-90
Potassium pyrophosphate	300-350
Potassium nitrate	7.5-12
Ammonia	1 - 4
Additives	Variable
pH	8-9
Operating Conditions:	
Temperature	125-135 °F
Anodes	OFHC Copper Titanium baskets
Current density	10-90 A/ft ²
Agitation	Air
Filtration	Yes
Color of solution	Iridescent blue/purple
Life	A few years

C. Pyrophosphate Copper Solutions

These plating solutions are almost exclusively used by printed circuit board manufacturers. Their major benefits include low copper concentration and the ability to deposit an even thickness over complex geometries, such as the top of a circuit board vs the inside of a drilled hole.

The majority of these solutions have been replaced with bright throw acid sulfate systems because the pyro solutions are much more difficult chemistries to analyze and control. You may find the solutions in some job shops as substitutes for cyanide copper strike solutions on zinc die castings or for copper striking zincated aluminum.

4. Brass Plating

Currently, there are no commercially viable processes for plating brass, and alloy of copper and zinc, other than from a cyanide based chemistry. Brass is applied mostly for decorative purposes, wherein it is subsequently stained to yield an "antique" or colored finish. Brass is also applied to enhance adhesion of rubber to steel. Brass readily tarnishes, so most often it is finished off with a coat of lacquer.

Brass Plating Solution (g/L)

Copper cyanide	30-60
Zinc cyanide	8-15
Sodium cyanide	15-30
Sodium carbonate	22-100
pH	10-11.5

Operating Conditions:

Temperature	125-135 °F
Anodes	Brass of same alloy composition as plated
Current density	5-15 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Pale yellow
Odor of solution	No specific
Life	Many Years

Bronze Plating Solution (g/L)

Copper cyanide	35
Potassium cyanide	80
Potassium stannate	42
Potassium hydroxide	12
Sodium potassium tartrate	45
pH	12+

Operating Conditions:

Temperature	150-160 °F
Anodes	Copper/carburized steel, graphite or stainless steel
Current density	20-100 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Pale yellow
Odor of solution	Pungent
Life	Many years

5. Bronze

Bronze (80% Copper 20% Tin) can only be plated from a cyanide based chemistry. The plating equipment is identical to that for copper, or brass plating.

6. Zinc Alloy

Alloys of zinc have been the major focus for a good substitute for cadmium plating. If an alloy of zinc contains a small amount of a more noble metal, such as nickel, tin, cobalt, or iron, the zinc retains its cathodic relationship with steel, but the alloying metal reduces the activity of the coating so that it corrodes sacrificially at a slower rate, thereby enhancing corrosion protection over plain zinc. There are numerous zinc alloy processes being touted as the best cadmium alternative, including zinc-nickel, zinc-cobalt, zinc-tin, and zinc-iron. Of these, zinc nickel appears to be a favorite at this time while some zinc-cobalt installations have been made. The others are either too expensive or do not produce a pleasing enough appearance to be applicable for anything other than as a paint undercoat for automobile body panels. The equipment for plating zinc alloys is identical to that used for nickel plating (see below).

A. Zinc-Nickel

Zinc-Nickel alloys can be plated from both alkaline and acidic chemistries, with the alkaline process the most often favored.

Alkaline Zinc-Nickel Solution (g/L)

Zinc	8-15
Sodium hydroxide	90-130
Nickel	1-1.5
Additives	As required
pH	14+

Operating Conditions:

Temperature	70-90 °F
Anodes	Zinc and steed
Current density	10-45 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Yellow
Odor of solution	No specific
Life	No Data (new process)

B. Zinc Cobalt

Acid Zinc Cobalt Solution (g/L)

Zinc chloride	75-90
Potassium chloride	200-250
Cobalt	2-3.5
Boric acid	22-30
pH	5-6

Operating Conditions:

Temperature	65-95 °F
Anodes	Zinc, bags
Current density	1-0 A/ft ²
Agitation	Air
Filtration	Yes
Color of solution	Pale with slight purple
Odor of solution	No specific
Life	No Data (new process)

7. Nickel

Nickel is most often plated from the "Watts" chemistry, although there are numerous other formulations, including a specialized "Woods Nickel Strike" that is used to obtain adhesion on stainless steels. The watts bath is used to obtain bright or semi-bright deposits for decorative applications. In decorative applications where deposit appearance and corrosion resistance are highly important, as on the exterior of an automobile, two or more layers of nickel from watts baths are applied. The most common such layered nickel plating referred to as "duplex nickel" which consists of two layers of nickel. The first layer is called semi-bright nickel, containing no sulfur bearing brighteners and the second layer is a fully bright nickel deposit containing a controlled amount of sulfur bearing brightener.

The duplex nickel is normally topped off with a thin coating of chromium plating. The bright nickel layer corrodes in favor of the semi-bright, protecting it galvanically and delaying the onset of corrosion of the base metal.

Another often used nickel plating formulation is the sulfamate based chemistry. It is used in electroforming or other applications where a nickel deposit containing no or low internal stress is desired.

Nickel is also used to plate "composite" deposits, where the plated nickel contains finely dispersed diamond dust or other abrasives such as silicon carbide. Such composite coatings are used to create long lasting cutting tools.

A. Watts Nickel

The watts nickel plating chemistry can contain a variety of additives to control pitting, yield

"leveling", and produce brightness from a medium (semi-bright) to a full mirror bright deposit. Additives are normally patented products sold by suppliers along with the plating chemicals.

Watts Nickel Solution (g/L)

Nickel sulfate	225-350
Nickel chloride	30-90
Boric acid	30-45
Additives	As required
pH	3-5

Operating Conditions:

Temperature	125-135 °F
Anodes	Nickel or nickel containing 0.02 % sulfur or others, bagged
Current density	25-100 A/ft ²
Agitation	Cathode rod or air
Filtration	Yes
Color of solution	Deep green
Odor of solution	No specific
Life	Many years

B. Wood's Nickel Strike This solution is purposely designed to generate high volumes of hydrogen gas, while depositing only a thin layer of nickel, even at the highest current densities. The major use is to obtain adherent thin nickel deposits that can then be plated with other metals.

Wood's Nickel Strike (g/L)

Nickel chloride	225
Hydrochloric acid	100-200 ml/L
pH	<.1

Operating Conditions:

Temperature	70-90 °F
Anodes	Nickel
Current density	100-300 A/ft ²
Agitation	None
Filtration	None
Color of solution	Dark green
Odor of solution	Sharp
Life	Years

Sulfamate Nickel Solution (g/L)

Nickel sulfamate	450-525
Magnesium chloride	8-15
Boric acid	45-55
Additives	As recommended
pH	3-5

Operating Conditions:

Temperature	125-135 °F
Anodes	Sulfur depolarized nickel
Current density	20-140 A/ft ²
Agitation	Air
Filtration	Yes
Color of solution	Deep green
Odor of solution	No specific
Life	Many years

C. Sulfamate Nickel

The sulfamate nickel chemistry is used mainly for electroforming purposes, although some electronic applications requiring a low stress nickel underplate for gold overplates also use this solution. The equipment for sulfamate plating is identical to that used for watts baths, with the exception that the sulfamate process will typically have a purification compartment

attached to the tank, incorporated into the tank, or alongside the tank. The purification compartment is about 1/5 the size of the plating tank and the solution is recirculated through the compartment, using the filtration system. In the purification compartment, electrolytic nickel anodes and dummy electrodes plate out metallic contaminants and the polarization occurring at the anodes decomposes some of the sulfamate ions into stress reducing compounds.

Sulfamate Nickel Strike

Nickel sulfamate	320 g/L
Sulfamic acid	150 g/L

Operating Conditions:

Temperature	50°C
Anodes	Electrolytic nickel
Current density	50 A/ft ²
Agitation	None
Filtration	Yes
Color of solution	Deep green
Odor of solution	No specific
Life	Years

D. Sulfamate Nickel Strike An alternate strike solution can be used to activate stainless steel (vs the Wood's Nickel Strike). This solution eliminates the hydrochloric acid, which causes a safety and ventilation hazard.

8. Chromium

Chromium plating generally falls into two categories: decorative and "hard". Both categories can and are being plated from the same chemistries based on hexavalent chromium, while decorative chromium can also be plated from one of several trivalent chemistry. The terms decorative and hard are confusing and really mean "thin" and "thick". All chromium plates have a hardness in the same range (900-1100 vickers). Decorative chromium is a very thin layer of chromium applied over a substrate that has been bright nickel plated. The appearance of decorative chromium, to a large extent, is due to the appearance of the nickel. The chromium is so thin (3-20 millionths of an inch), that is essentially transparent. Decorative chromium plating equipment is identical to that of hard chromium. An exception is the trivalent decorative chromium, which typically has no exhaust system and requires continuous filtration.

"Hard" chromium should be called engineering chromium, because it is usually applied when a hard wear resistant metallic coating is required on a part that is subject to abrasive forces during service. A typical example is the chromium applied to hydraulic shafts for heavy equipment, on the piston rings of internal combustion engines, and on the shafts of landing gears of aircraft. A typical

chromium plating tank is constructed of steel with a PVC lining. It is equipped with heating elements and an exhaust system to remove the chromic acid fumes from the workers' breathing zone.

Chromium Plating Solutions (Hexavalent)

Chromium trioxide	225-260
Sulfate	2.25-2.6
Operating Conditions:	
Temperature	125-135 °F (for hard plating applications, temp. may be at 140 °F)
Anodes	Lead
Current density	Decorative 100-150 A/ft ² , Hard 150-250 A/ft ²
Agitation	None (Hard may use some air agitation)
Filtration	No
Color of solution	Deep dark red-brown
Odor of solution	No specific
Life	Many years
Mixed catalyst solutions:	
Chromium trioxide	30-45 oz/gal
Sulfate	.15-.18 oz/gal
Fluoride	.13 oz/gal

Note: Fluoride may be present as one or more of a variety of fluoride containing compounds.

Operating condition/life Same

A. Hexavalent Chemistries

The hexavalent chromium plating chemistries fall into two categories: conventional, and mixed catalyst. The conventional is a simple chemistry that anyone can mix up and use. The mixed catalyst chemistries are patented processes that have a few advantages, including faster plating, less problems caused by current interruption, and fewer problems plating onto passive nickel deposits. They also tend to be more difficult to control and expensive to operate. In hard chromium applications, mixed catalyst solutions also tend to etch steel in areas where plating is not intended, making masking more critical.

B. Trivalent Chemistries

Trivalent chemistries were developed in response to concerns about the detrimental effects of hexavalent chromium on the environment and workers' health. Hexavalent chromium is a powerful oxidizer that readily

attacks human tissues and has been linked in some studies to lung cancer. Trivalent chromium has a much lower toxicity level, is not an oxidizer and has to date not been linked with cancer. Platers have been slow to accept trivalent chromium as substitutes for hexavalent chemistries because they tend to plate deposits that are noticeably darker or not consistently of the same color. Since trivalent solutions are only used for decorative applications, this is a major drawback, but solution manufacturers have made great progress toward solving these problems. A major benefit from trivalent processes is that these solutions contain very low concentrations of chromium (about 1/5th as much), and the chromium can be waste treated without reduction step, so waste treatment and sludge disposal cost are reduced. Equipment generally consist of a rubber or plastic lined steel or plastic tank, an air agitation system, heating and cooling system, and a filtration system.

Trivalent Chromium Plating Solutions (g/L):

TC additive	400
Chromium concentration	20
TC stabilizer	8% vol
TC-SA	1.2% vol
TC regulator	1 ml/L
pH	3.2

Operating Conditions:

Temperature	70-90 °F
Anodes	Graphite (Harshaw), lead in membrane cell (Enthone-OMI)
Current density	90-200 A/ft ²
Agitation	Air
Filtration	Yes
Color of solution	Deep blue-green
Odor of solution	No specific
Life	Many years

9. Gold

Gold can be plated from three major chemistries: alkaline cyanide, neutral and acid. All three chemistries utilize gold from potassium gold cyanide salts. A proprietary gold plating process that does not utilize potassium gold cyanide is on the market, but is expensive to operate and limited in alloying capability. Most gold plated is an alloy of gold and some other metal or combination of metals such as nickel, cobalt, copper and silver. Gold can be plated in any commercial "Karat"

desired. The neutral and acid gold plating chemistries utilize chelating agents to perform the tasks normally performed by cyanide, control of metallic impurities and alloying elements. While these chelates could cause waste treatment problems, they rarely enter the wastewater treatment system in high concentrations, since most gold plating operations have meticulous recovery systems to use as little rinsewater as possible and recover the plating chemicals.

A. Alkaline Cyanide Chemistry

This solution is most often used to apply a thin film of gold over bright nickel in decorative applications such as jewelry. The plating tank is a typical layout with a plastic or lined steel tank, filtration, cathode rod agitation (optional), and heating elements.

Cyanide Gold Plating Solution (g/L)

Potassium gold cyanide	1-4
Potassium cyanide	1-12
Potassium carbonate	22-200
Additives	As required
pH	10

Operation Conditions:

Temperature	125-150 °F
Anodes:	Gold or stainless steel or platinized titanium
Current density	1-35 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Dark yellow
Odor of solution	No specific
Life	Many years

B. Neutral Gold Plating Chemistry:

These solutions are favored for barrel plating applications of high purity gold.

Neutral Gold Plating Solution (g/L)

Potassium gold cyanide	8-12
Monopotassium phosphate	75-90
Potassium citrate	60-76
pH	6-6.5

Operating Conditions:

Temperature	125-135 °F
Anodes	Platinized titanium
Current density	1-3 A/ft ²
Agitation	Cathode rod/ recirculation pump
Filtration	Yes
Color of solution	Pale yellow/clear
Odor of solution	No specific
Life	Many Years

C. Acid Gold Plating

Acid gold solutions can produce a variety of gold deposits, including the hardest, most wear resistant. They are favored for plating of printed circuit board connectors and in the semi-conductor industry.

Acid Gold Plating Solution (g/L)

Potassium gold cyanide	4-8
Citric acid	30-60
Ammonium citrate	30-35
pH	3-5

Operating Conditions:

Temperature	90-140 °F
Anodes	Platinized titanium or platinized niobium
Current density	1-5 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Range from clear to purple
Odor of solution	No specific
Life	Many years

Silver Plating Solution (g/L)

Silver cyanide	8-30
Potassium cyanide	15-30
Sodium carbonate	22-100
Potassium hydroxide	8-15
Potassium nitrate	0-15
pH	12-14

Operating Conditions:

Temperature	70-90 °F
Anodes	Silver
Current density	1-40 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Dark brown/black
Odor of solution	Organic
Life	Many years

10. Silver

While non-cyanide silver plating chemistries based on sulfites or succinimides have been available for some time, most all silver plating is presently being performed in the cyanide chemistry. The non-cyanide solutions are far more expensive to install and operate and can not tolerate contamination to the same degree as the cyanide process. The plating equipment is typically a lined steel or plastic tank equipped with a filter and cathode rod agitation. Silver can also be barrel plated.

11. Tin

Tin can be plated from more than four major chemistries: the alkaline stannate process, the fluoborate, the proprietary "halogen" and sulfonate processes, and the sulfuric acid based process. The alkaline stannate, flouborate, and sulfate chemistries are most often encountered in job shops. The alkaline stannate process typically consists of a heated steel tank, while the sulfuric acid based process uses a plastic or pvc lined steel tank and has filtration. The alkaline process produces a mat, pure tin deposit that has excellent solderability, while the sulfate process produces mat or bright deposits with lesser or marginal solderability but superior appearance. The alkaline process is a bit more difficult to operate than the sulfate process. The alkaline solution is favored for barrel plating applications, although the flouborate solution can also be used.

Compositions (oz/gal) and operating conditions are:

Alkaline Stannate (g/L)

	Rack	Barrel
Potassium stannate	100	200
Potassium hydroxide	15	22
Potassium carbonate	22-100	22-100
Additives	none	none
pH	>14	>14

Note: 2-4 g/L of cyanide is sometimes added to reduce the effects of metallic contaminants

Operating Conditions:

Temperature	150-180 °F
Anodes	Tin
Current density	1-100 A/ft ²
Agitation	Cathode rod
Filtration	No
Color of solution	Pale yellow or clear
Odor of solution	No specific
Life	Many years

Fluoborate Tin Solutions (rack/barrel plating) (g/L)

Tin (from concentrate)	30-45
Fluoboric acid	200-250
Boric acid	22-40
Additives	As recommended, but required
pH	<.1
Operating Conditions:	
Temperature	90-120 °F
Anodes	Tin
Current density	1-80 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Pale yellow
Odor of solution	No specific
Life	Many years

Acid Sulfate Tin Solutions (g/L)

Stannous sulfate	15-45
Sulfuric acid	7.5-22
Additives	As recommended, but required
pH	< 0.1
Operating Conditions:	
Temperature	55-85 °F
Anodes	Tin
Current density	1-25 A/ft ²
Agitation	Cathode rod
Filtration	Yes
Color of solution	Pale yellow/clear
Odor of solution	Sweet
Life	Many years

12. Tin-Lead

Tin-Lead is applied to electronic components that require high solderability. The plating hardware is a typical plating setup with continuous filtration optional. There are two basic chemistries the alloy is plated from: the fluoboric and the (proprietary) sulfonic acid based chemistries. These solutions are most commonly found in printed circuit board manufacturing shops and job shops specializing in plating for electronics. The electronics industry uses a "high throw" formulation to allow for plating inside drilled holes. Others use a conventional solution that yield the best solderability. The fluoborate solution is made by mixing liquid flunborate concentrates with water.

Tin-Lead (Solder) Solutions (g/L)

	Conventional	High Throw
Tin (from concentrate)	52-60	12-20
Lead (from concentrate)	22-30	8-14
Fluoboric acid	100-150	350-500
Boric acid	22-40	22-40
pH	<.1	<.1
Operating Conditions:		
Temperature	70-90 °F	
Anodes	Lead-tin alloy	
Current density	15-25 A/ft ²	
Agitation	Cathode rod	
Filtration	Yes	
Color of solution	Pale yellow	
Odor of solution	Sweet	
Life	Many years	

Electroless Plating Processes

One major drawback to electroplating is the non-uniform coating produced, because electric current tends to concentrate on sharp edges, corners and points. Electroless plating processes are used when it is necessary to obtain a very uniform coating on complex geometries, because these processes do not depend on electricity delivered from a rectifier. As the name implies, the coating is produced without an outside source of current. The reducing electrons are chemically provided.

Some electroless deposits are also more corrosion resistant than their electroplated counterparts. The following are two of the most often applied electroless processes:

A. Electroless Nickel

Electroless nickel is applied to numerous complex electronic and industrial components for the high degree of wear resistance and corrosion protection. An example is the sliding plates that "mold" the hamburger patties served in fast food restaurants. Two plates slide against each other forming the cavity that is used to "injection mold" the patty. The plates slide against each other at lightning fast speeds. Electroless nickel is also used in the plating of plastics, to provide the first metallic layer on the plastic to yield conductivity for subsequent deposits.

The electroless plating process normally consists of two plating tanks and a nitric acid storage tank. Each plating tank contains heating elements, an air sparger and a recirculating filter. The solution will eventually deposit nickel on everything it contacts, so periodically the tank walls and associated equipment must be stripped with nitric acid (thus the nitric acid storage tank). The plating solution has a finite life (8-14 "turnovers"), after which, it must be waste-treated or disposed of through a commercial disposal firm. The electroless nickel plating solution contains strong chelating agents that interfere with a conventional wastewater treatment system, so they must be treated separately using electrowinning, proprietary treatment methods, or special chemical treatments. The rinsewater from electroless nickel operations is usually separated and treated separate from other rinsewater.

Nickel-Phosphorous Electroless Solutions (g/L)

Nickel sulfate	21	11.8
Acetic acid	9.3	
Lactic acid	27	
Molybdic acid	.009	
Propionic acid	2.2	
Lead acetate	.001	
1,3 Diisopropyl thiourea	.004	
Sodium hypophosphate	24	22.3
pH	4.6	5.5
Temperature	95 °C	95 °C
Life	Weeks/months	

Electroless nickel is typically plated from one of two basic chemistries, yielding either a nickelphosphorous alloy (most common) or a nickel-boron alloy. Each alloy can be plated from a number of different solutions to yield varying alloy compositions. Shown are typical formulations:

Nickel-Boron Electroless Solutions (g/L)

Nickel chloride	30
Sodium hydroxide	40
Ethylene diamine	86 mg/L
Sodium borohydride	0.6
Thallium nitrate	0.007
Sodium gluconate	15
Diethyl amine borane	1.0
Lead acetate	0.02
pH	13-14
Temperature	90 °C
Life	Weeks/months

B. Electroless Copper

The major use for electroless copper is in the manufacture of printed wiring boards. The electroless copper is used to apply a thin coating of copper over the top-side and into the drilled holes of the boards. The drilled holes are initially non-metallic, since the boards are made of epoxy-fiberglass. With the electroless copper the holes become conductive for further plating. Equipment for electroless copper plating usually consists of a polypropylene or PVC plastic tank and filter. Some solutions operate at room temperature, so heating is not required, others require heating. The rinsewater and spent electroless copper often contain chelating or complexing agents, so waste treatment becomes difficult.

A typical composition (g/L) electroless copper solution is:

Electroless Copper Solutions (g/L)

Coppersulfate:	13.8	5
Rochelle salts	69.2	25
Sodium Hydroxide	20	7
MBT	.012	
Formaldehyde	38ml/L	10 ml/L
Temperature	50 °C	25 °C
Life	Weeks/months	

C. Others

There are numerous other electroless plating solutions in the literature, although they are rarely used. The following solutions may be encountered:

Electroless Cobalt (g/L)

Cobalt sulfate	30
Ammonium chloride	84
Sodium hypophosphate	20
pH	10
Temperature	95 °C
Life	Weeks/months

Electroless Silver (g/L)

Silver cyanide	1.34
Sodium cyanide	1.49
Sodium hydroxide	0.75
Dimethyl amine borane	2
Temperature	55 °C
Life	Weeks/months

Electroless Gold (g/L)

Potassium gold cyanide	5.8
Potassium cyanide	13
Potassium hydroxide	11
Potassium borohydride	21.6
Temperature	75 °C
Life	Days





P2 Concepts & Practices For Metal Plating & Finishing

**A Pollution Prevention Training Course for the "Common
Sense" Initiative—
Metal Plating and Finishing Sector—
Under the Environmental Technology Initiative**

**Developed through a partnership between the Office of Research and
Development of the U.S. Environmental Protection Agency & The
American Electroplaters and Surface Finishers Society**

Introduction to Pollution Prevention

Notice

The U.S. Environmental Protection Agency, through its Office of Research and Development, partially funded the preparation of these training materials under Assistance Agreement No. CT902900 to the American Electroplaters and Surface Finishers Society (AESF). It has not been subjected to the Agency's peer and administrative review, and therefore does not necessarily reflect the views of the agency. No official endorsement should be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction to Pollution Prevention

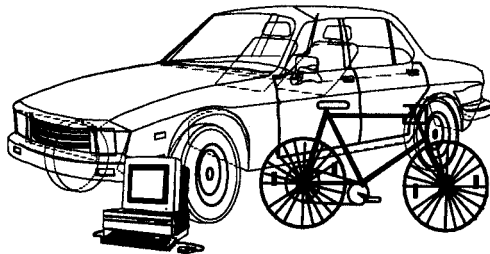
**by Derek Vachon, Water Technology
International Corp., Burlington, Ontario,
Canada**

Slide 1

This lecture module was produced by Mr. Derek Vachon, Water Technology International Corp., Burlington, Ontario, Canada.

This lecture is part of a training course in Pollution Prevention for Metal Finishers, produced by the AESF, under a grant from the U. S. Environmental Protection Agency (U.S. EPA) Environmental Technology Initiative. AESF is very grateful to Ms. Teresa Harten and Mr. Brian Westfall of the Office of Research & Development, Risk Reduction Engineering Laboratory, Cincinnati, Ohio, for their assistance and support of this project. The AESF also wishes to thank the more than 100 AESF volunteers who devoted many long hours to peer-review these materials, and guide the authors. Acknowledgment is also given to Concurrent Technologies, Inc. CAMP, Inc. and the National Association of Metal Finishers (NAMF) for their support of this endeavor.

Pollution Prevention in Metal Finishing



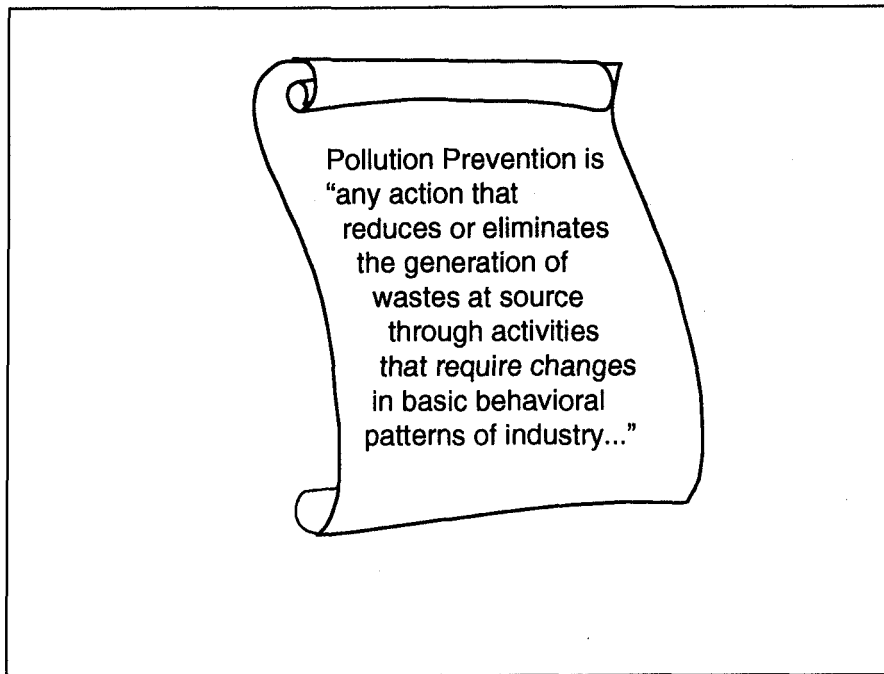
Slide 2

Introduction

Pollution control in the metal finishing industry has traditionally been recognized as an end-of-pipe, add-on need for the facility. Responding to the public's concerns in the 1980s, municipal sewer plants have demanded stringent limitations on contaminant discharges into the sanitary sewer system from metal finishers. To meet these increasingly tighter regulations, metal finishing facilities have installed treatment systems that precipitate metals into sludge.

This material, deemed hazardous, is then disposed of in ever-more restricted landfills. The costs associated with this manner of pollution control is an ever-increasing burden on metal finishers.

Waste minimization, such as reduction and recycling efforts, are a start to better waste management in this industrial sector. The next step is to prevent pollution by finding less toxic systems and by using new or better techniques to eliminate, reduce, reuse or recycle potentially harmful materials.



Slide 3

Definition

Pollution prevention is defined as "any action that reduces or eliminates the generation of pollutants or wastes at source, achieved through activities that promote, encourage or require changes in the basic behavioral patterns of industry, commercial and institutional generators or individuals." (Ontario Ministry of Environment and Energy, MOEE, 1993)

The EPA defines pollution prevention as "The use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source."

"[Pollution prevention] includes practices that reduce the use of hazardous materials, energy, water or other resources, and practices that protect natural resources through conservation or more efficient use." (US EPA, 1991).

"Pollution prevention is the prevention of the generation of wastes from industrial, commercial and residential activities, including the avoidance of crossmedia transfer of pollutants." (CA)

" [Pollution prevention] shall include, but need not be limited to, raw material substitution, product reformulation, production process redesign or modification, in-process recycling, and improved operation and maintenance of production process equipment. [It] shall not include any action or change entailing a substitution of one hazardous substance, product or non-product output for another that results in the creation of substantial new risk, and shall not include treatment, increased pollution control, out-of-process recycling, or incineration, except as otherwise provided pursuant to subsection f. of section 7 of this act." (NJ, 1991)

Pollution Prevention

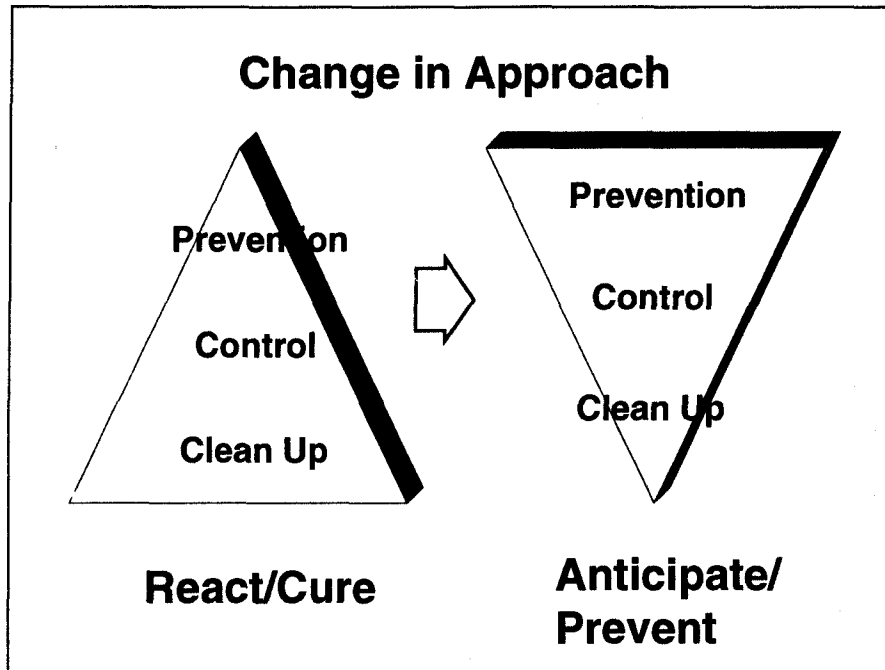
- **Change in business approach**
- **Improve product quality**
- **Conserve valuable resources**
- **Eliminate, reduce pollution**

Slide 4

What is pollution prevention?

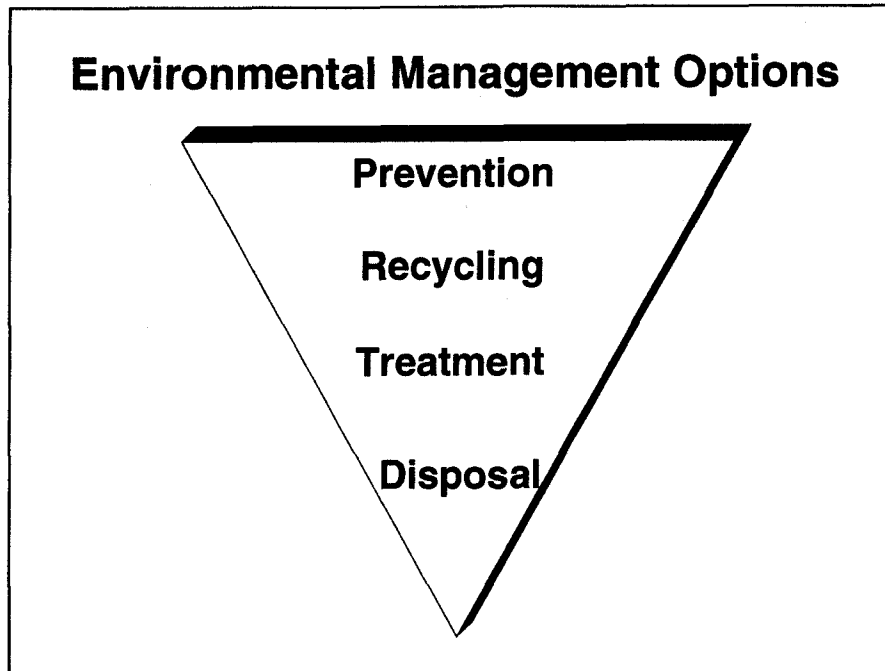
Pollution prevention is more than preventing pollution of the environment. It is a change in the way business is done so that quality improvements are achieved at the same time that losses of valuable resources are prevented.

Preventing pollution at the boundary of the facility (end of pipe) is the old manner of business. Now addressing production methods and determining all *potential* sources of wastes and the means of eliminating or controlling these is the proper means of pollution control.



Slide 5

Pollution prevention is a conceptual shift in environmental management from a “react and cure” philosophy to an “anticipate and prevent” model. This new model focuses on prevention of contamination rather than on its control and cleanup, as was typically done in the past. Activity is directed into identifying potential environmental concerns and addressing defined priorities rather than operating the facility and awaiting the “knock on the door” from the regulator who arrives to inform you of a possible violation. Anticipating and resolving potential environmental problems before they become a serious concern is the prime objective of this program. This is far superior than waiting for a problem to happen and then spending significantly more dollars in reaching a solution.



Slide 6

Environmental Management Options

The hierarchy presented in the figure demonstrates the preferential choice in environmental management. The top level is pollution prevention. The next level shows recycling, where in-plant recycling is considered pollution prevention, while off-site recycling is considered waste management and is not technically pollution prevention. The lesser favored choice is in-house end-of-pipe treatment. Finally, managed and secure disposal is the last option available for waste control. Efforts must be focused on addressing environmental issues from the top down. Namely, look at preventing the problem much sooner than finally having to concern yourself with disposing of the waste.

?? What is Pollution Prevention ??

- **Changes in . . .**
 - . . . processes
 - . . . equipment
 - . . . operations
 - . . . raw materials
 - . . . products
- **In-process reuse**
- **In-plant recycle**

Slide 7

Pollution prevention involves assessing the opportunities for changes in the production processes. These include:

- Changes to less toxic bath chemistries;
 - Continual maintenance or cleanup of these process baths;
 - New equipment, processes or materials;
 - Better techniques in metal finishing that result in lower contaminant losses;
- and
- Considerations in processing different products, ones that will result in reduced pollution.

Examples of these changes are: Raw material substitution, product reformulation, production process redesign or modification, improved operation and maintenance of production process equipment.

In-process reuse of process chemicals is recognized as pollution prevention. Chrome plating solution that is recovered from a drag-out tank and returned to the plating bath is a prime example. In-plant recycle will also result in pollution prevention.

A Quiz:

List The Benefits of P2



- Reduced liability
-
-
-
-
-
-
-
-

Slide 8

Before proceeding, it is time to do a quick in class quiz to determine the class participants' understanding of benefits of pollution prevention. This is an interactive exercise with the lecturer recording all suggestions that are offered by the class members.

(Use a flip chart or whiteboard to record suggestions. Remember that in this brainstorming session, no suggestion is incorrect. Suggest that class participants record the suggestions in their manual.)

Why do pollution prevention?

- **Reduce costs**
- **Protect employees**
- **Reduce liabilities**
- **Satisfy customers**
- **Improve morale**
- **Enhance image**

Slide 9

Why do pollution prevention?

The incentives to promote pollution prevention in a facility are many. There are a number of benefits to adopt pollution prevention. Some of these are:

- Reducing resource losses results in raw material savings and savings in expenses.
- Protecting employees from the potential hazards of some chemicals used by this industry sector.
- Reducing losses of resources from the process minimizes potential discharges of pollutants into the environment.
- Reducing wastes will reduce present and future environmental liabilities.
- Customers are requesting environmental accountability from suppliers.
- Overall employee morale will improve.
- The public's view of the company will improve as concerns are resolved.

Student exercise:

List additional benefits:

A Quiz:
List The Barriers to P2

- Cost
-
-
-
-
-
-
-
-
-

Slide 10

A similar class interactive exercise can be used to solicit suggestions from participants on barriers to pollution prevention. Note that the list of barriers appears to be significantly larger than the benefits.

Barriers to Pollution Prevention

Barriers have been recognized as impediments to implementing pollution prevention actions in metal finishing facilities. These barriers typically fall under one or more of the following general categories. Some examples of barriers for each category are presented.

Regulatory Barriers

- End-of-pipe focus
- Regulator's inflexibility
- Environmental fees and/or fines
- Existing laws and regulations

Institutional Barriers

- Lack of management support
- Poor communications to all staff
- Focus only on production
- Lack of trust with regulators

Operational Barriers

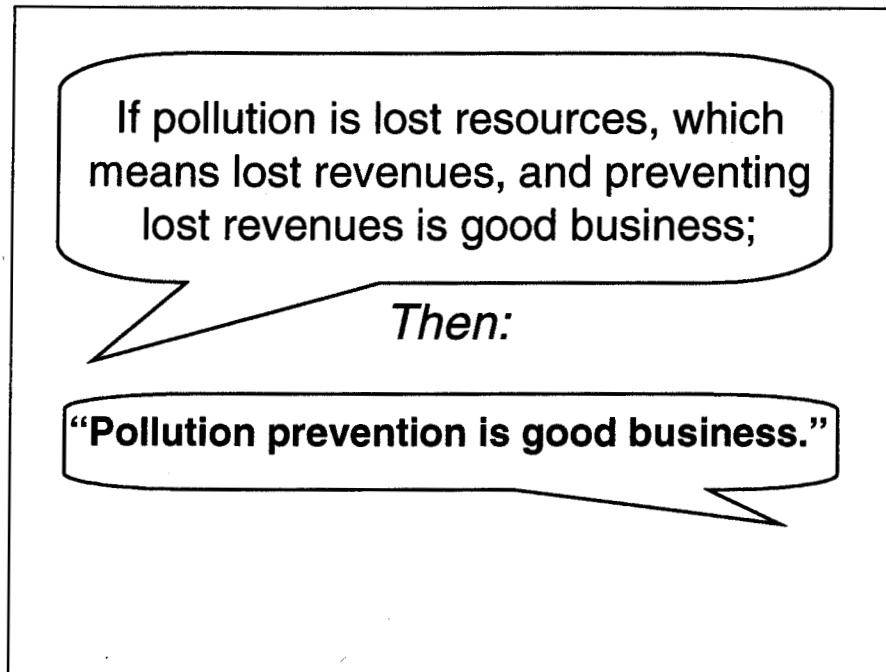
- Lack of operator training
- Availability of equipment, processes
- Material and equipment limitations
- Production downsizing

Economical Barriers

- Lack of short payback period
- Market risk
- Return on investment incentives
- Expensive alternatives

Student exercise:

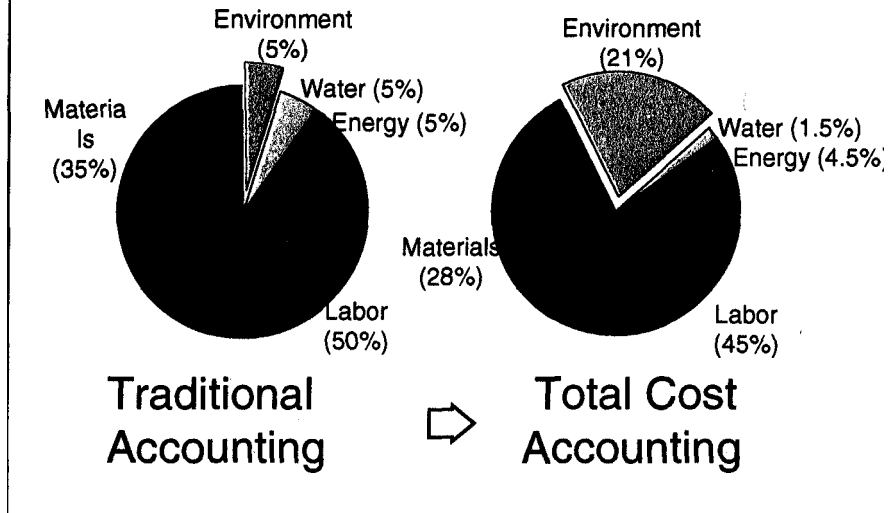
List additional barriers:



Slide 11

Pollution is basically losses of valuable raw materials or resources. If you prevent these losses, you prevent pollution and you save dollars. Saving dollars should help you realize greater profits, if not just allowing you to actually realize profits, instead of business losses. This axiom sums up the financial benefits of pollution prevention.

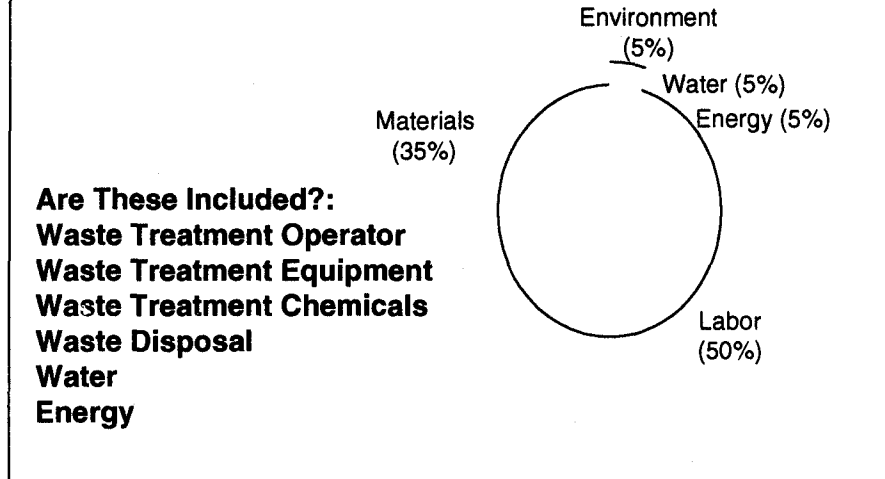
Typical Costs in Metal Finishing



Slide 12

Typical environmentally related costs associated with metal finishing are traditionally recognized as about 5 % of the total costs of production. These costs are generally based on labor and materials associated with end-of-pipe treatment and monitoring. These costs can also include waste treatment equipment purchases, amortized over some period of time. Some platers report as low as 2.5 to 2.8 % of costs. In these cases, however, administration costs and other overhead expenses are never included. Total cost accounting presents a more realistic assessment of environmental costs that include administrative and overhead expenses, as well as the value of lost materials and resources, which contribute to pollution management. Total cost accounting, in effect, addresses the true cost of pollution. The following pages address the economics of pollution prevention by evaluating each factor that contributes to the operating costs in a metal finishing facility.

Typical Costs in Metal Finishing



Slide 13

To put the actual costs of environmental control into true focus, let's look at the individual components of the production costs. The normally understood breakdown of costs in the metal finishing industry is presented in Slide 13. Labor, materials, water, energy and the environment are the common factors considered in the costs associated with metal finishing. Capital equipment expenditures (and/or depreciation) also contribute to environmental costs.

Typically, environmental costs are determined as extra charges, that reduce profits after all other expenses have been calculated in the selling price of the product. Generally, these costs amount to about 5 % of the total company expenditures.

Generally included in the environmental costs are:

- In-process capital equipment;
- End-of-pipe waste treatment capital equipment (amortized over 10 years);
- Labor associated with operating the waste treatment systems;
- Chemicals used directly in the treatment of wastes;
- Water and energy used directly in the operation of waste treatment facilities;
- Hazardous waste disposal;

[In-class activity: Students can suggest other environmental costs]

-
-

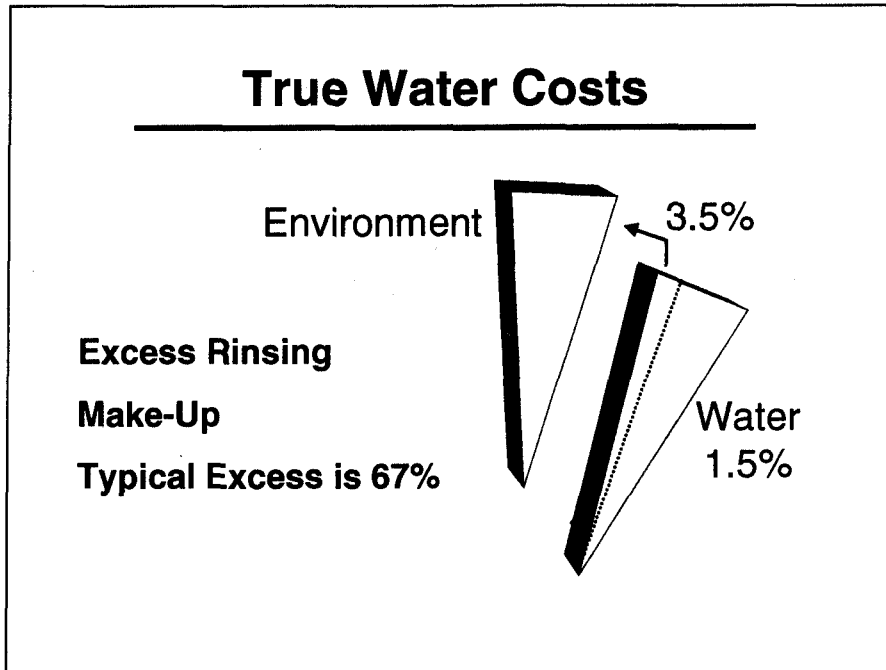
Are these costs real? To assess this question, each of the four individual cost factors, (excluding environment), must be carefully evaluated.

Environmental costs are often included in other categories, and, as a result, often are understated.

Demonstrated on the following slides are some of the areas where environmental costs may be hidden:

- Water
- Energy
- Materials
- Labor

By identifying the environmental component of each of these areas and “transferring” the relevant costs to the environmental category, we can begin to understand how significant costs can be. The opportunity—and desire—to address and manage these costs more effectively becomes an important part of the cost of doing business.



Slide 14

Water Costs

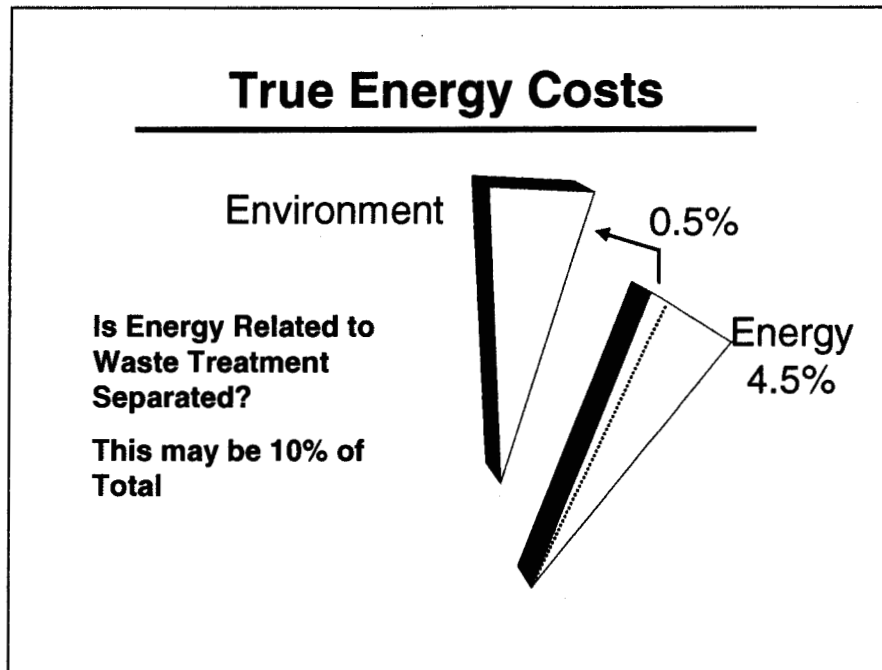
The major uses of water are in the make-up of the process baths and in rinsing the parts in transit from one bath to the next. Another use of water in a metal finishing shop is for personal hygiene and sanitary purposes, which is about 10 gal/day per person. For a medium-sized facility (50 employees), this usually represents only about 1 to 2 % of the total daily water usage.

The major water use in a metal finishing facility is for rinsing parts. As a result, the water becomes contaminated with plating solutions and other lost resources. Often the volume used in most shops is excessive. Significant reductions in water usage can be achieved by a number of methods, and these are described in the Module on Housekeeping. It is very reasonable to consider that water usage can be cut by as much as two-thirds of the current levels used in rinsing.

The second major usage of water is for the make-up of process solutions. The volume of water needed for this purpose is directly related to the quality needs of the process solutions (the frequency of preparation of fresh solutions). If process bath quality is maintained at an effective level, the need for a fresh bath can be minimized. In other words, process bath maintenance results in reduced water needs.

All rinse water and exhausted process bath solutions must be managed in a wastewater treatment process. Excessive use of water actually represents an additional environmental cost. Assuming that at least two-thirds of the water can be reduced in a facility by better rinsing practices and improved bath maintenance, the true water cost in the production process is more likely only 1.5% of the total cost in metal finishing, with the residual 3.5% transferred to the environmental costs (Slide 14).

Zero discharge will also lead to significant reduction of water use. Methodologies are presented in other modules that provide descriptions of water reduction options.



Slide 15

Energy Costs

Energy needs in the metal finishing industry include electricity used for:

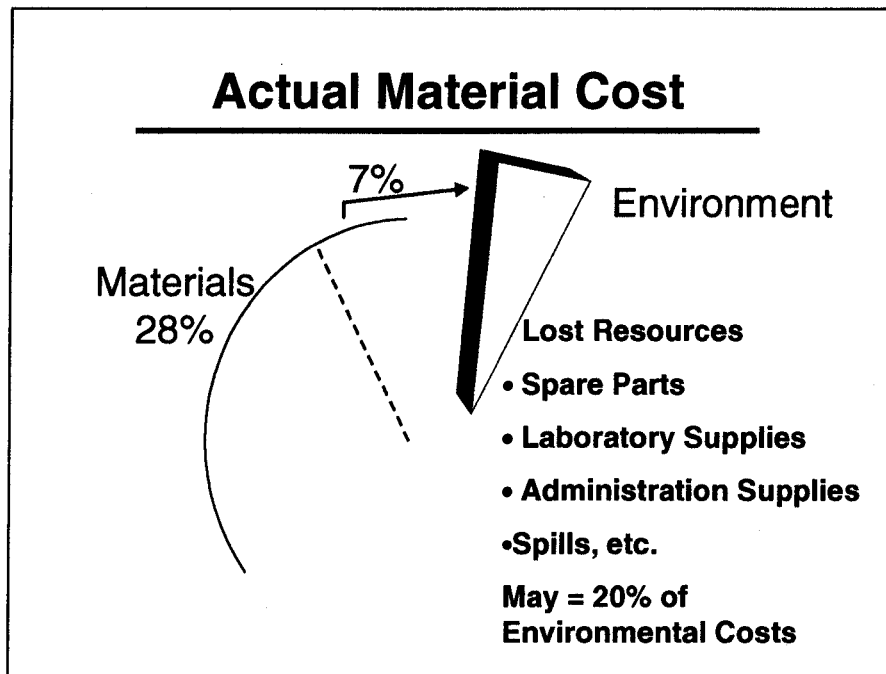
- Plating and other metal processing;
- Office support, computers;
- Pumps, mixers, motors, etc.;
- Maintenance;
- Lighting;
- Ovens

Other sources of energy include fuels such as oil and gas. These are used in the industry for:

- Heating;
- Steam production;
- Transportation

Electrical energy is also needed to operate the waste treatment systems, but this probably represents only a small fraction of the total energy bill and is seldom identified separately. These costs may be as high as 10 % of the total energy bill, however, and because they are directly related to environmental management, this fraction of the energy costs should be transferred to the environment.

[In-class activity: Students can suggest other energy users and identify the portion that should be charged against environmental expenditures.]



Slide 16

Materials Costs

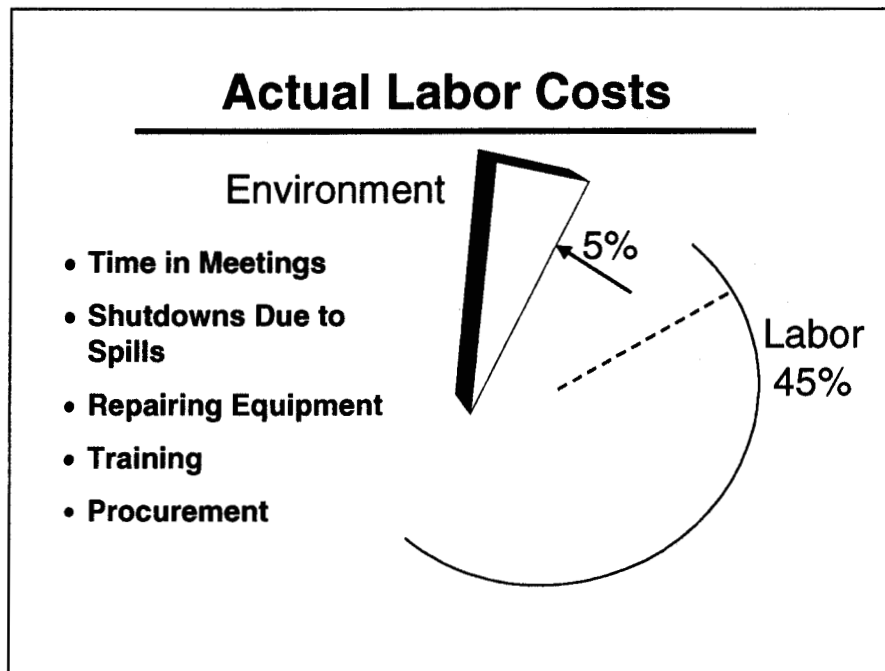
Equipment and supplies that are used in all aspects of the production of the final product are included in this factor. This component includes:

- Raw materials and chemicals;
- Hardware and miscellaneous equipment;
- Spare parts;
- Laboratory and miscellaneous supplies;
- Administration needs;
- Proprietary chemicals;
- Anodes

Waste treatment chemicals and major capital equipment associated with waste management are typically accounted for under environmental expenditures. Miscellaneous supplies such as motors, pump parts, wiring, plumbing, etc., however, are part of the maintenance shop inventory and may not be included in the environmental expenses. Lost raw materials are the major source of pollution, and these can range from 10 to 50% (in extreme cases) of the purchase of raw materials. An example of high material loss and the economical impact is described in a subsequent section of this module. An average of 20% for loss of raw materials and process chemicals is not unrealistic. Therefore, of the 35% annual expenses related to materials, about 7% is directly related to pollution management. This fraction should be transferred to the environmental costs.

Note that for some facilities, the 7% may be considered a conservative or low value and could actually be a much higher number, depending on the processes conducted in the finishing facility and the sophistication (or lack thereof) of the systems.

(In-class activity: Students can suggest other material costs and identify the portion that is related to environmental charges.)



Slide 17

Labor costs typically associated with environmental expenditures include:

- Operation/management of waste pretreatment facilities;
- Laboratory analyses of final effluents;
- Reporting, reviewing environmental issues;
- Legal staff

Labor expenses that may not be included, but are directly related to environmental issues can include:

- Management discussions about the environment;
- Employee discussions, meetings on the environment;
- Shutdowns caused by spills or environmental problems;
- Time spent on reworking products;
- Training

This could represent as much as 10 % of the total labor effort at a facility. This fraction should also be identified with the environmental costs.

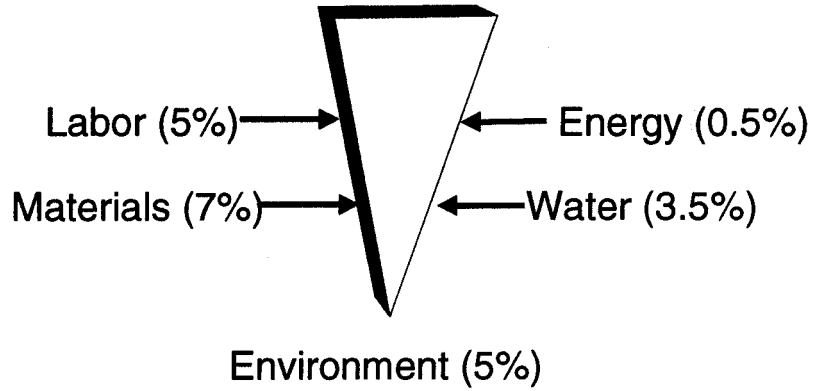
Finally, miscellaneous costs that may be included in the routine production costs, but not in environmental charges could be:

- Capital equipment (and/or amortized fees);
- Capital cost of floor space or facility expansions;
- Overhead charges on waste treatment equipment space;
- Others; students to suggest

These costs can also represent a significant portion of unaccounted environmental charges.

(In-class activity: Students can suggest other labor-related costs and identify the portion related to environmental charges.)

Summary of Cost Transfers

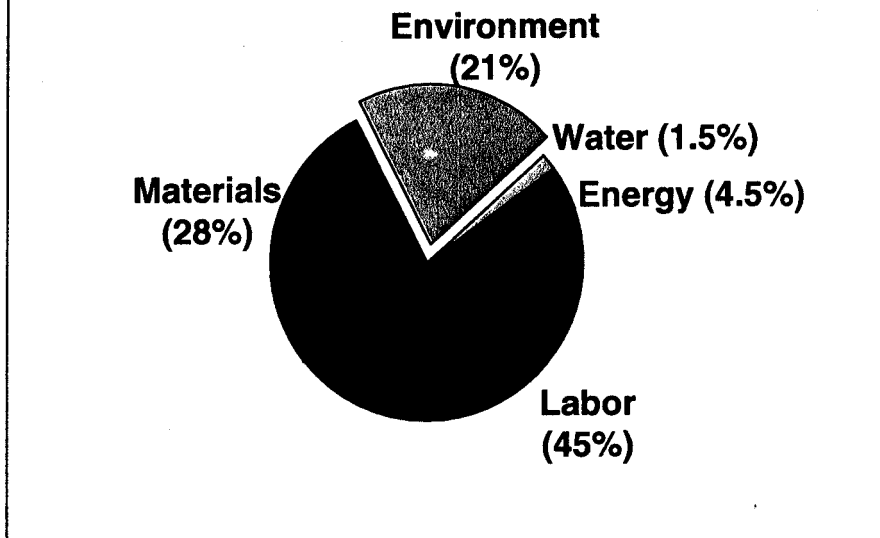


Slide 18

Environmental Costs

It was initially identified that environmental expenditures are about 5 % of the annual cost of the metal finishing business. Some significant "transfers" of costs, however, have been identified from each of the other cost factors.

Realistic Costs in Metal Finishing



Slide 19

The result is a more realistic cost division as presented.

Note that part of total cost accounting for environmental expenditures also addresses other financial commitments such as:

- Future environmental liability;
- Insurance;
- Health and safety;
- Other intangible costs, such as reduced value to property and land, air or water use.

Economics of Pollution Prevention

To treat 1 lb of CrO ₃ , requires:	Cost/lb	COST
1.47 lb of metabisulfite	\$	\$
0.80 lb of sulfuric acid	\$	\$
1.20 lb of caustic soda	\$	\$
CrO ₃ cost per lb or proprietary chromium cost	\$	\$
Sludge disposal "	\$	\$
TOTAL COST		\$

** 1 lb of CrO₃ generates 2.94 lb of sludge (35% solids)
 Excluding the costs of labor, electricity, water and capital equipment costs, the real cost of wasting 1 lb of CrO₃ represents _____ x cost of the purchase of fresh CrO₃.

Slide 20

Impact of Lost Materials

Let's look at another approach to assessing the true costs of pollution by determining the costs associated with the purchase of plating chemicals and the costs associated with the necessary treatment of losses of these chemicals. For this example, hard chrome plating will be reviewed.

In a hard chrome plating operation, the plating efficiency is about 15 to 25%. Techniques that are used to keep the majority of the CrO₃ in the system include dragout tanks with evaporation and return to the process baths. However, Some CrO₃ will frequently be lost from the system, however. The amount lost depends upon the effectiveness of the rinsing system, and bath maintenance processes and volume of drag-out. Also, losses from chrome bath mist control systems can be a significant source of resource loss. Values ranging from 20 to 50 % are not uncommon for CrO₃ losses from this type of plating. Let us look at the economics associated with CrO₃ plating.

Chrome plated on the workpiece is the desired objective and this represents the business.

- CrO_3 is purchased for \$3.00/kg. (Proprietary blends can cost up to \$ 6.00/kg.)

Chrome that is not plated on the workpiece, but lost from the system, must be controlled. This represents a cost.

- Cr^{+6} must be reduced to Cr^{+3}

Costs associated with this requirement include specific reducing chemicals, capital equipment, control systems, additional water, energy demands and manpower.

- Cr^{+3} must be precipitated from solution.

Costs associated with this requirement include additional precipitating chemicals, additional capital equipment capacity¹, additional water and energy demands.

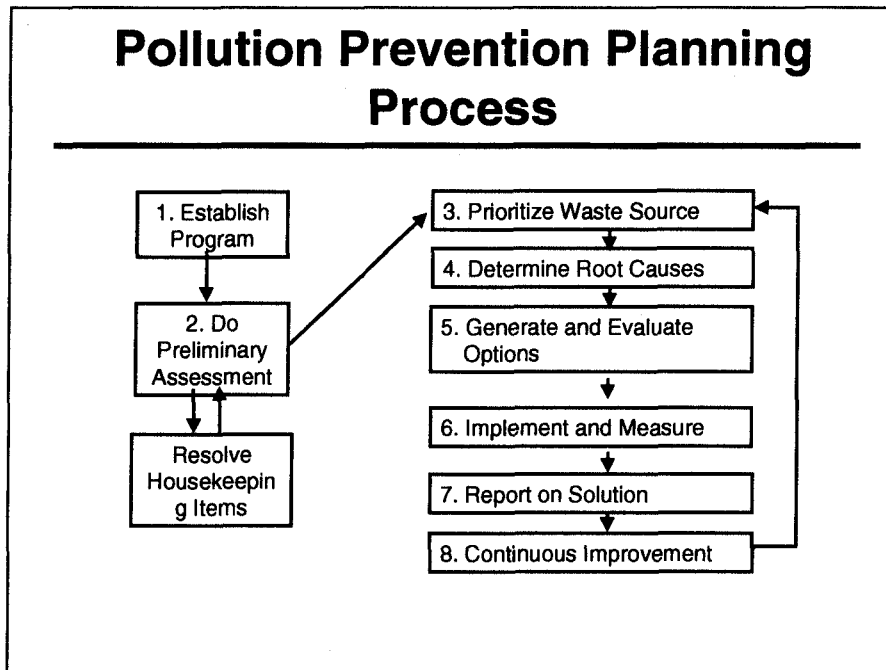
- Cr^{+3} bearing sludges must be disposed.

Costs associated with this requirement include additional capital equipment capacity and energy, and hazardous waste disposal costs and/or transportation costs to a recycling facility.

Adding up the costs gives a value to the CrO_3 of two to three times the initial purchase price of the chemical. A facility then has two prices for CrO_3 : A lower-valued material that ends up on the product and a higher-valued material (up to three times that of the lower value) that ends up "in the garbage." It was mentioned previously that CrO_3 losses can range from 20 to 50 %, and these losses of CrO_3 represent a significant cost to a metal finishing facility. Applying pollution prevention practices that result in reducing the chrome losses means minimizing the "purchase" of the more expensive chrome.

Other economical considerations:

- While companies that handle hazardous wastes are extremely competitive at this time, long-term costs are likely to rise.
- By addressing pollution prevention, the life of existing equipment can probably be extended. New equipment will, in all likelihood, be more expensive than equipment purchased 10 years ago. By reducing the wear on equipment, repair and maintenance costs will decline.
- Water and sewage rates will rise in the future. Decreasing water consumption now is a sure way to control the impact.



Slide 21

Pollution Prevention Planning

Pollution prevention planning is a simple, cyclic, eight-step process, built on the premise of continuous improvement. When followed, it will assist the metal finisher in establishing prevention activities in his/her plant. The focus has been placed on the reduction of toxic substances used, generated or released from the metal finishing plant. The outcome of the process will be a comprehensive, multi-media pollution prevention plan. The eight steps are:

- (1) Establishing the program, following management commitment to pollution prevention;
- (2) Assessing the current operations, identifying available in-house information, and developing a comprehensive list of potential wastes;
- (3) Prioritizing wastes for further consideration;
- (4) Determining root causes of wastes;
- (5) Identifying potential pollution prevention solutions;
- (6) Implementing and measuring remedial actions;
- (7) Reporting on the success of the pollution prevention program and actions taken to date;
- (8) Ensuring that the process is a continuous improvement program.

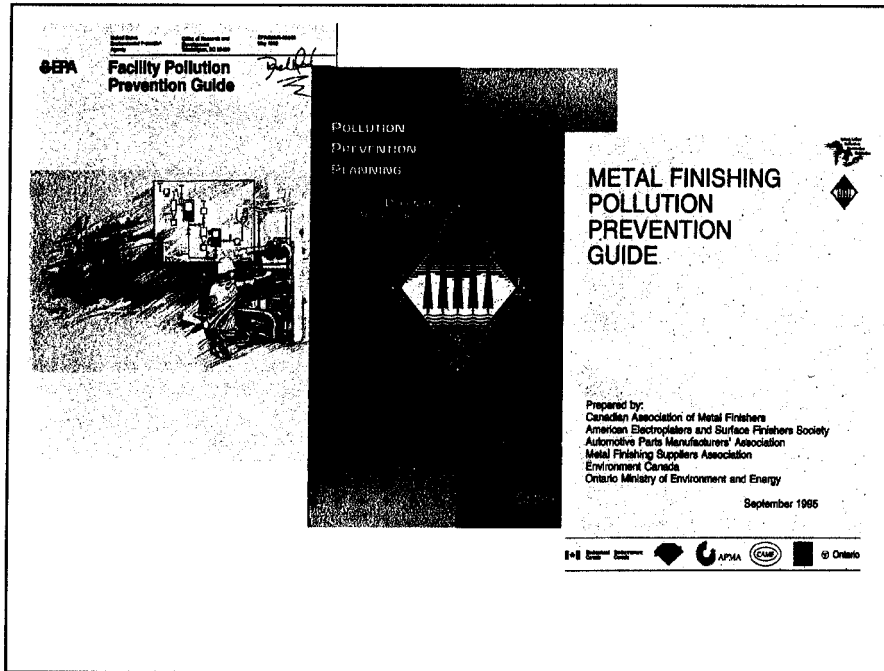
This step-by-step approach offers a set of procedures to incorporate pollution prevention planning into a metal finisher's business plan. It is prescriptive enough to be followed directly, but is general enough that the principles presented can be modified to suit the specific business planning currently being done at all facilities. For each step, tools and tips that have been developed by or for the metal finishing industry are described and/or provided to make the work easier.

As is apparent, this concept is simply an extension of the basic principles of Total Quality Management (TQM) or Total Quality Environmental Management (TQEM). By applying these principles to the assessment of pollution in a facility, the company's employees are motivated to become involved in the entire pollution prevention process. The program will be effectively accomplished in a team approach, through close interaction with fellow employees. This is one of the essential elements of a TQEM system. Other elements include:

- Education and employee empowerment;
- Prioritizing and implementing options;
- Use of success stories, recognition, reporting;
- Continuous improvement.

It is recognized that this approach may appear onerous for small companies, but this should not be the case. Very small operations can still follow this model, using smaller "teams" and realistic efforts based on their company size. For companies that lack experience with TQM, a contractor can be retained to act as a facilitator of the program and can still provide valuable benefits for an effort as minimal as 1/2 day per month.

The important point in this approach is to follow a series of steps in identifying all potential waste concerns and systematically rank and manage these wastes to the greatest benefit to all concerned.



Slide 22.

Based on the Pollution Prevention Planning Process, and on similar processes described in the U.S. EPA "Facility Pollution Prevention Guide (U.S. EPA, 1992b) and the Ontario Ministry of the Environment and Energy's Pollution Prevention Guide (MOEE, 1993), a Metal Finishing Industry Task Force (under the Canadian Great Lakes Pollution Prevention Initiative*) developed an industry-specific guide describing the procedures to use in employing pollution prevention in a metal finishing facility (MFI, 1994). This manual offers:

- Introduction with explanation of P2 and Guidebook;
- Description of step-by-step procedures for each of 8 stages of a planning process, including examples;
- Appendices with all tools, blank forms and supplemental information, definitions;
- Additional appendices with resource, etc.

The U.S. EPA's Facility Pollution Prevention Guide (U.S. EPA, 1992b) offers some of this same information. In addition, other U.S. EPA documents and U.S. State Pollution Prevention centers can provide material on this subject.

*See Acknowledgments on p. 41.

Step 1. Establish Program

- **Obtain company commitment**
- **Identify participants**
- **Set priorities and objectives**
- **Establish schedule**
- **Communicate with employees**

Slide 23

Pollution Prevention 8-Step Process

An overview of each of the eight steps of the Pollution Prevention Planning Process is presented in the following. The detailed description of the facility assessment is described in a later module.

The pollution prevention process is a continual evaluation of how a company's business is done, and as such, requires a strong commitment from senior management to be accepted. Co-operation and personal commitment from all departments is necessary, and a committed pollution prevention team is essential to ensure success.

A number of activities must be undertaken in Step 1, including:

- In order for the program to be successfully implemented at the facility, management must be committed to its objectives and willing to provide all necessary resources.
- A cross section of all staff will facilitate new ideas and ensure that what happens on the shop floor verifies what is perceived by management.
- The goals and priorities must reflect the needs of the company, management and staff with respect to improving overall environmental management. They must also be consistent with production requirements and the most cost-effective use of material inputs.

The identification of objectives and the development of the priorities should be done at the initial meeting of the facility Pollution Prevention Team. By "brainstorming" with all team members, a list of overall objectives, in no particular order, can be generated. Priorities should be agreed upon and these ranked in a selected order of importance.

- Develop a schedule to undertake the plan and keep everyone working toward the established goals. Establish a realistic and achievable action plan to carry out the program. Set objectives within a time frame that encourages activity and does not establish a burdensome or unrealistically difficult time period to accomplish.
- It is important to communicate to all company levels so that everyone is made aware of the goals of the program. Achieving success is much more likely, as a result. The process must be non-blaming. Those connected with past wasteful procedures must not be fearful regarding their previous practices and be willing to contribute to new solutions.

Step 2. Preliminary Assessment

- **Complete Environmental Checklist**
- **Do Site Inspection**
- **Inventory wastes**
- **Collect in-house data**
 - inventory information
 - plant layout
 - process flow diagram
 - sewer diagram
 - bath chemistries
 - MSDS
- **Resolve "housekeeping" issues**

Slide 24

Step 2 focuses on a preliminary assessment of the facility and identifies all potential waste sources and streams. The following tasks will be completed in this step:

- A self-assessment of in-house environmental management practices;
- A review of the facility layout and the production processes;
- Identification of inputs to the facility (raw materials, etc.) and outputs (products, wastes, etc.);
- A detailed site inspection to identify and quantify waste sources and streams;
- Preparation of a "complete" waste inventory.

This step is a cyclic activity of information sessions, site inspections and analysis to develop a waste inventory. First, identify all aspects of the production and waste management systems. Follow the information session with a site inspection and analysis session. Finally, the Team will use its observation skills and unique insights to develop a "grocery list" or inventory of wastes. Repeat the information session, site visit and analysis session until the inventory is completed. The information and analysis session should make use of the available in-house information and manuals such as: Equipment and process operating manuals, bath chemistry recipes, MSDS data, purchasing records, waste manifest records and knowledgeable staff.

At this stage create or update a schematic process flow diagram of each production line to reflect the current operations. The diagram provides insight into the waste generating processes. A sewer diagram should also be obtained or produced that identifies the waste discharges and their receiving environments.

During the site inspection, external personnel, who are not constrained by the everyday operation of the facility, can provide a very useful contribution. These people have not grown complacent to the way a particular company's business is conducted, and they often recognize problem areas that company personnel have long ago forgotten or now take for granted.

The products from the second step will be:

- (1) A list of Improved Operating Practices (IOPs)— opportunities that will offer the facility high returns on limited efforts; and
- (2) A comprehensive list of potential waste sources requiring further evaluation.

Step 3. Prioritize Waste Sources

- **Review available data**
- **Short-list wastes**
- **Establish selection criteria**
- **Team "brainstorm"**
- **Identify priorities**

Slide 25

In Step 3, the facility's Pollution Prevention Team will reduce the long inventory of wastes developed in the previous step to a short list of primary concerns based on the company's priorities. Prioritizing is a process whereby one looks at the various aspects of a waste such as quantity, cost of treatment or disposal, raw material cost, how hazardous or toxic is it, safety concerns, plus others, and with a numerical rating system leads one to a logical conclusion as to what to do first. A prioritization approach that works in metal finishing facilities is a two-step procedure:

- (1) The Team uses a set of criteria based on environmental concerns to reduce the long inventory of waste sources from Step 2 to a short list of waste sources to be dealt with.
- (2) The Team uses a second set of criteria based on impact or cost benefits and changeability to reduce and rank the short list of wastes to the list that will be addressed.

The product from this step will be a short list of one or two prime waste concerns.

Step 4. Determine Root Causes

- **Root cause analysis**
 - **Brainstorm**
 - **Fishbone**
 - **Multi-voting**
- **Verify information**
- **Collect relevant data**

Slide 26

In Step 4, the Team examines the potential causes of each primary waste concern identified in the previous stage. It is important to consider all possible root causes for each waste and to determine the most significant causes. The Team will use TQEM tools, such as Pareto Charts, brainstorming, and fishbones to identify the principal root causes.

The product(s) from this activity are the most significant causes that will form the basis for identifying pollution prevention solutions.

Step 5. Generate and Evaluate Options

- **Generate options**
- **Screen alternatives**
 - **Criteria**
 - **Supplier help**
 - **“Brainstorm”**
- **Identify favorable option**
 - **Options analysis**
- **Recommend to management**

Slide 27

The purpose of Step 5 is to generate a comprehensive list of pollution prevention actions, perform a cost/benefit analyses of each and recommend suitable actions for the elimination or reduction of the primary waste sources identified in Step 3. The lists of most significant causes from Step 4 for each waste stream are used to generate options for reducing or eliminating each waste stream.

It is important to look first for the pollution prevention alternatives involving source reduction/elimination and internal recycle/recovery. These options are the most likely to generate solutions with the greatest benefits.

The product from this step will be the pollution prevention option(s) that can be presented for management approval. Included in the recommendation to management is information on the economic and technical feasibility of the most promising solutions. Approval in principle for the allocation of the capital funds for the project is then sought, and where appropriate, the team puts together a detailed implementation plan for the recommended solution.

Step 6. Implement and Measure

- **Implementation plan**
- **Final approval**
- **Install solution**
- **Measure solution**

Slide 28

Once the solutions have been selected, prioritized, recommended to management and approved, the Pollution Prevention Team must develop a program to incorporate them into the daily operations of the plant. While the projects may have been approved in principle, it is at this stage that final approval and allocation of funds is obtained.

It is important to advise the rest of the company about the proposed changes. Plans will vary in complexity with the magnitude and type of task. Simple housekeeping problems, such as segregation of wastes, are not as complicated as implementing a plan involving the replacement of a piece of processing equipment or the installation of a metal recovery system.

In this step, the team generates a detailed implementation plan and cost estimate for the approved solution. They also prepare a communications plan to inform management and employees about the project and a monitoring program to measure the success of the project. The implementation, monitoring and communications plans, cost estimate and approval forms are submitted to management for approval.

Step 7. Report on Solution

- **Management**
- **Employees**
- **Public**

Slide 29

In Step 7, with an eye to continued improvement in pollution prevention for the metal finishing sector, the success of this on-going process will hinge on the reported findings. The log that should be kept need not be formal; minutes of operational meetings or even diary notations may be sufficient to note the performance of any changes.

In this step, the team may need to generate reports for management, employees and the public on the progress of the pollution prevention solution. Note that the public will include your customers, and many of them now require that suppliers have an in-house environmental plan.

Step 8. Continuous Improvement

- **Integrate into Corporate Plan**
- **Next Priority**
 - **Repeat Steps 3 to 7**
- **Awareness**

Slide 30

Step 8 involves the task of maintaining and improving a viable pollution prevention program. It is made easier with the integration of pollution prevention into the corporate plan and the establishment of a pollution prevention awareness program. Training and employee and management education programs will help in accomplishing this task.

The process of pollution prevention does not stop with the successful completion of the first activity undertaken, but involves the incorporation of pollution prevention into the daily metal finishing business.

Summary

Pollution prevention involves a change in the way the metal finishing industry views waste generation. Pollution prevention addresses waste as a loss of raw materials, which is basically like throwing money down the sewer. Rather than focus on resolving waste problems with an "end-of-pipe" treatment system, metal finishers must recognize that reducing resource losses at the source makes sense both economically and environmentally.

There are many benefits to pollution prevention, and progressive metal finishers should not ignore the potential of this philosophy. Short-term benefits that will help convince facility management of the value of the process focus around Improved Operating Practices (IOPs). Over the long term, a proactive approach in identifying and prioritizing problems and resolving these will help the metal finisher company achieve the goals of pollution prevention.

References

MFI Task Force, "Metal Finishing Pollution Prevention Guide." (1994).

MOEE, "Pollution Prevention Planning - Guidance Document and Workbook" (training manual for discussion purposes). ISBN 0-7778-1441-2 (1993).

U.S. EPA, "Waste Minimization Opportunity Assessment Manual." EPA/625/7-88/003 (1988).

U.S. EPA, "Pollution Prevention 1991 - Progress on Reducing Industrial Pollutants." EPA 21P-3003 (1991).

U.S. EPA, "Pollution Prevention Resources and Training Opportunities in 1992." EPA/560/8-92-002 (1992a).

U.S. EPA, "Facility Pollution Prevention Guide." EPA/600/R-92/088 (1992b).

Acknowledgments

Many individuals and organizations are owed thanks for support and contributions that led to the development of this training manual. This course was initially developed to support the use of the Canadian Metal Finishing Pollution Prevention Guide that was created by the members of the Metal Finishing Industry Pollution Prevention Task Force. Many individuals contributed to the Pollution Prevention project representing several organizations, including: American Electroplaters and Surface Finishers Society, Automotive Parts Manufacturers Association, Canadian Association of Metal Finishers, Environment Canada and Ontario Ministry of Environment and Energy. Individuals from these organizations who contributed directly with authorship of the Guide included:

Pauline Brown, Environment Canada, Ontario Region

Brian Calver, Dovercourt Electro-Plating Co. Ltd.

Mark Cotter, Automotive Parts Manufacturers Association

Ken Coulter, Ken Coulter Consulting

Mike Dejak, ECO-TEK Inc.

Dan Dolan, Wastewater Technology Centre

Jack Dupuis, B.J. Dupuis & Associates Inc.

Bruce Gillies, Ontario Ministry of Environment & Energy

Brian LeClair, Ontario Ministry of Environment & Energy

Ken Lemke, UMR Systems Inc.

Anita Li, Environment Canada, Ontario Region

Derek Vachon, Wastewater Technology Centre

Walter Wikaruk, W.R. Wikaruk Consulting

The principal authors of the introductory modules in this Training Course on Pollution Prevention in Metal Finishing included: Derek Vachon, Dan Dolan and Ken Lemke, who were ably supported by staff from their organizations. Appreciation is offered for the efforts of: **Carl Yanch**, **Mark Preston**, **Samira Nawar**, **Tom Constable**, **Sherri Gibson**, **Kim Taylor** (WTC), **Jane Lemke** (UMR) and **Marty Borruso** (Plating Systems, Inc.)

Preparation of the case study and video of "SAMCO" was possible through the efforts of Jim Hotchkies (Sheridan College), Ken Lemke and Derek Vachon, with support from the Sheridan College video arts department and three metal finishers who offered their facilities for video filming.

The development and testing of the Training Course was made possible through the support of a number of organizations, including:

- American Electroplaters and Surface Finishers Society
- Environment Canada
- New York City Industrial Technology Assistance Corporation
- Ontario Ministry of Environment & Energy
- Plating Systems, Inc.
- UMR Systems Inc.
- Wastewater Technology Centre

