

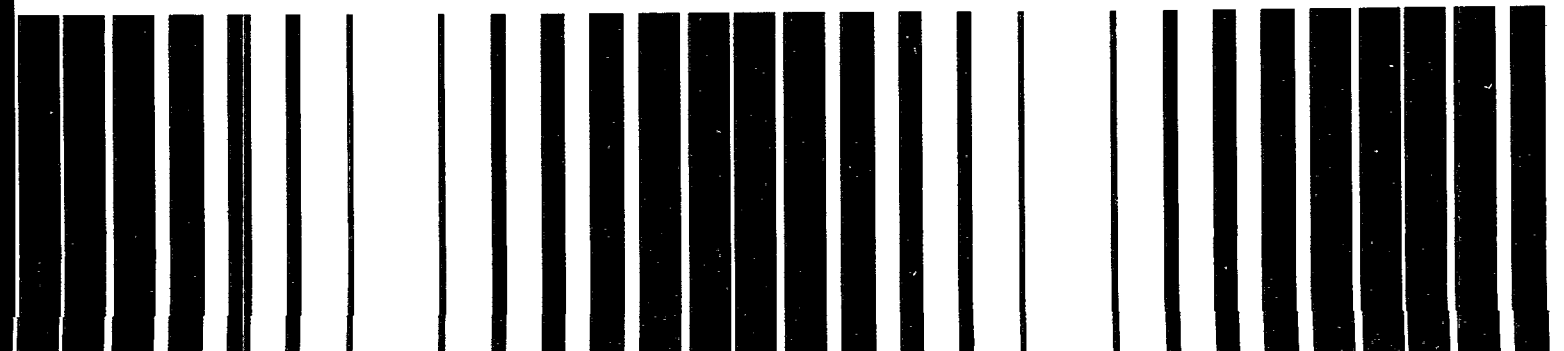
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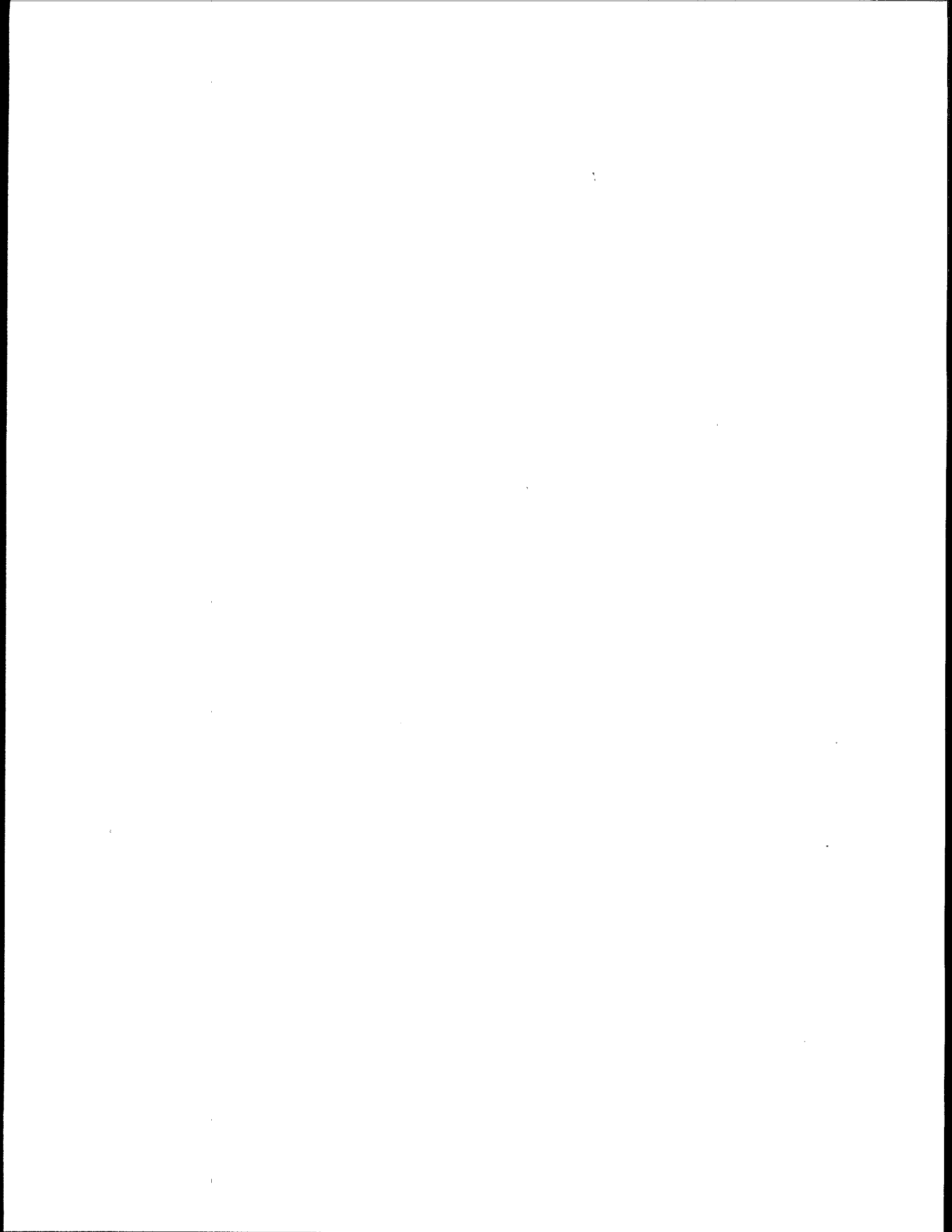
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# **Guides to Pollution Prevention**

## **The Fabricated Metal Products Industry**





EPA/625/7-90/006  
July 1990

**GUIDES TO POLLUTION PREVENTION:  
THE FABRICATED METAL PRODUCTS INDUSTRY**

**RISK REDUCTION ENGINEERING LABORATORY  
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## NOTICE

This guide has been subjected to U.S. Environmental Protection Agency's peer and administrative review, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. This document is intended as advisory guidance only to the fabricated metal products industry in developing approaches for pollution prevention. Compliance with environmental and occupational safety and health laws is the responsibility of each individual business and is not the focus of this document.

Worksheets are provided for conducting waste minimization assessments of metal fabrication facilities. Users are encouraged to duplicate portions of this publication as needed to implement a waste minimization program.

## FOREWORD

This guide provides an overview of the metal fabrication processes and operations that generate waste and presents options for minimizing waste generation through source reduction and recycling. Such processes are an integral part of aerospace, electronic, defense, automotive, furniture, domestic appliance, and many other industries. Fabricated metal processes generate various hazardous waste streams, including oily wastes from machining operations, heavy metal-bearing streams from surface treatment and plating operations, and additional wastes related to paint application.

Reducing the generation of these wastes at the source or recycling the wastes on- or off-site will benefit the metal fabricating industry by reducing raw material needs, reducing disposal costs, and lowering the liabilities associated with hazardous waste disposal.

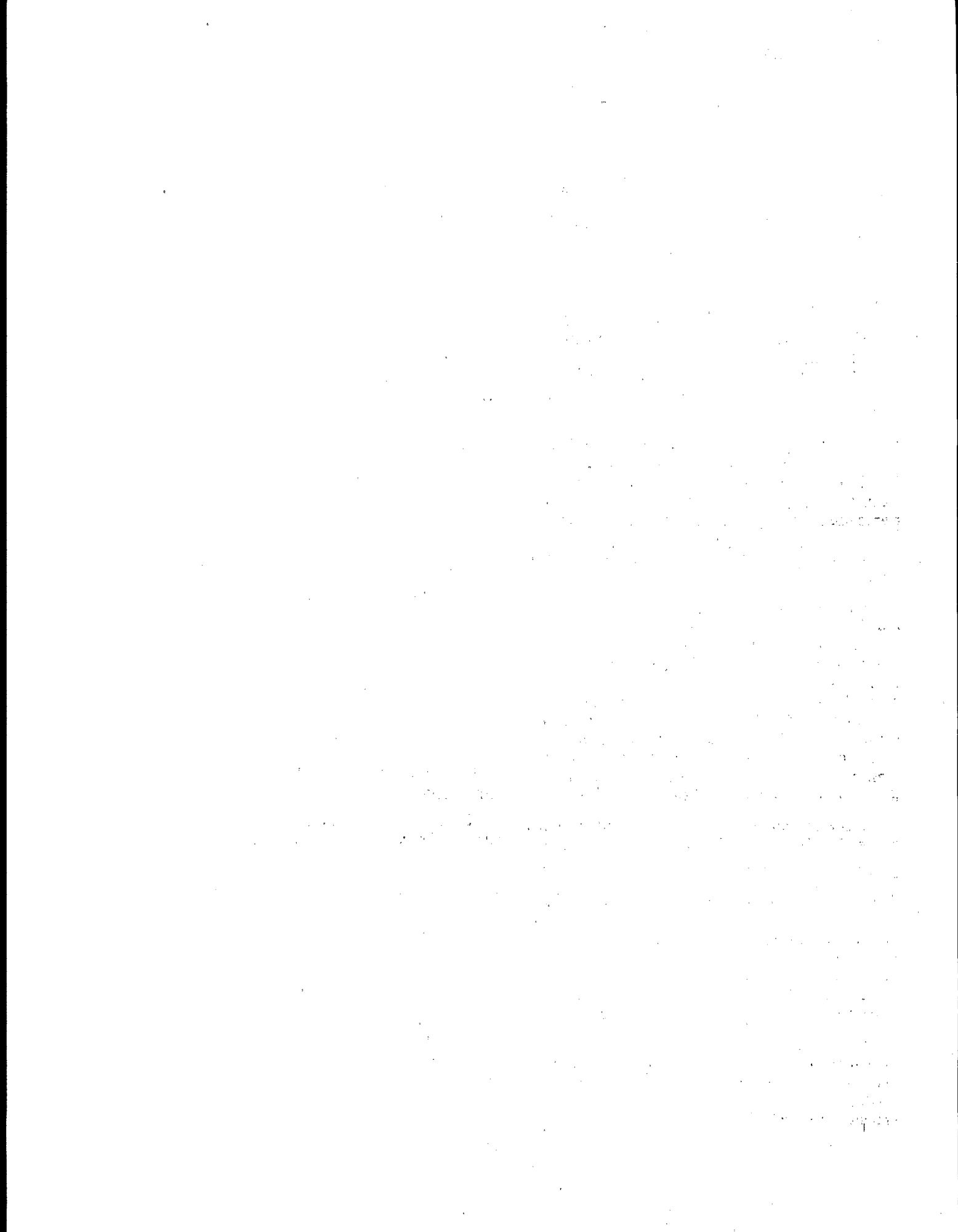
## ACKNOWLEDGMENTS

This guide is based in part on waste minimization assessments conducted by Jacobs Engineering Group, Inc. Pasadena, California for the California Department of Health Services (DHS). Contributors to these assessments include: David Leu, Benjamin Fries, Kim Wilhelm, and Jan Radimsky of the Alternative Technology Section of DHS. Much of the information in this guide that provides a national perspective on the issues of waste generation and minimization for metal fabricators was provided originally to the U.S. Environmental Protection Agency by Versar, Inc. and Jacobs Engineering Group, Inc. in "Waste Minimization - Issues and Options, Volume II," Report No. PB87-114369 (1986). Jacobs Engineering Group Inc. edited and developed this version of the waste minimization assessment guide, under subcontract to Radian Corporation (USEPA Contract 68-02-4286). Jacobs personnel contributing to this guide include: Carl Fromm, project manager; Michael Meltzer, principal author; Michael Callahan, contributing author; and Sally Lawrence, technical and production editor.

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## SECTION 1 INTRODUCTION

This guide was prepared to provide plant operators or environmental engineers of commercial fabricated metal facilities with guidelines and options to minimize both hazardous and non-hazardous wastes. Others who may find this document useful are regulatory agency representatives and consultants.

The worksheets and the list of waste minimization options were developed through assessments of Los Angeles area firms commissioned by the California Department of Health Services (DHS 1989). The firms' operations, manufacturing processes, and waste generation and management practices were surveyed, and their existing and potential waste minimization options were characterized. Economic analyses were performed on selected options.

Four types of processes used in metal fabrication are examined in this guide: machining operations, parts cleaning and stripping, metal surface treatment and plating, and paint application. These processes use a variety of hazardous materials, including metal-working fluids, solvents, alkaline and acid cleaning solutions, treatment and plating solutions that contain hazardous metals such as chromium and cadmium, as well as cyanide and other chemicals, and paints containing solvents and heavy metals. Many of those hazardous substances are being phased out in some applications, in favor of more benign compounds.

Waste minimization is a policy specifically mandated by the U.S. Congress in the 1984 Hazardous and Solid Wastes Amendments to the Resource Conservation and Recovery Act (RCRA). As the federal agency responsible for writing regulations under RCRA, the U.S. Environmental Protection Agency (EPA) has an interest in ensuring that new methods and approaches are developed for minimizing hazardous waste and that such information is made available to the industries concerned. This guide is one of the approaches EPA is using to provide industry-specific information about hazardous waste minimization.

EPA has also developed a general manual for waste minimization in industry. The *Waste Minimization Opportunity Assessment Manual* (USEPA 1988) tells how to conduct a waste minimization assessment and develop options for reducing hazardous waste generation at a

facility. It explains the management strategies needed to incorporate waste minimization into company policies and structure, how to establish a company-wide waste minimization program, conduct assessments, implement options, and make the program an on-going one. The elements of waste minimization assessment are explained in the Overview, next section.

In the following sections of this manual you will find:

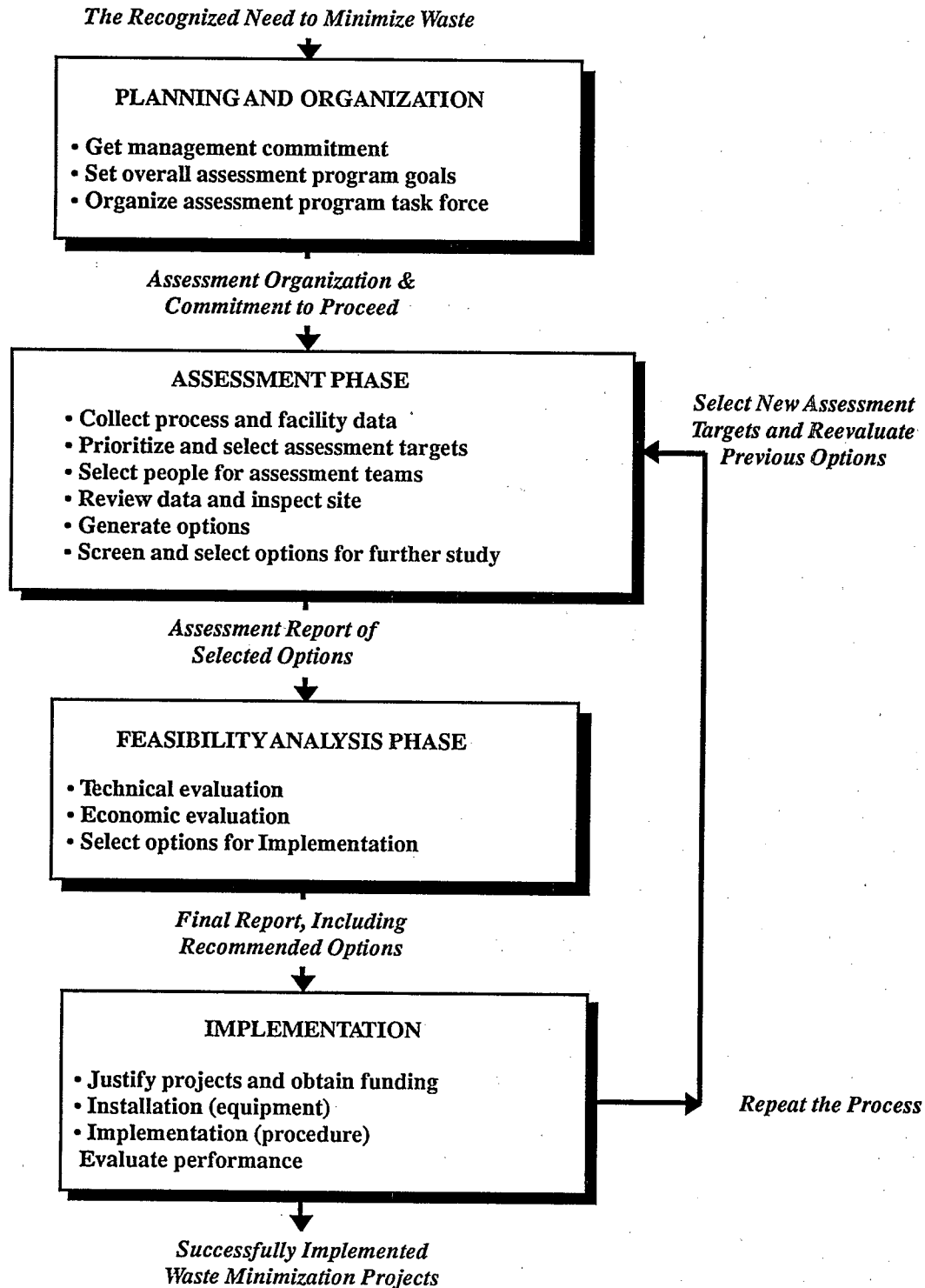
- An overview of the fabricated metal industry and the processes used in it (Section Two);
- Waste minimization options for the industry (Section Three);
- Waste Minimization Assessment Guidelines and Worksheets (Section Four)
- An Appendix, containing:
  - Case studies of waste generation and waste minimization practices of three facilities;
  - Where to get help: Sources of useful technical and regulatory information

### Overview of Waste Minimization Assessment

In the working definition used by EPA, waste minimization consists of source reduction and recycling. Of the two approaches, source reduction is usually considered preferable to recycling from an environmental perspective. Treatment of hazardous waste is considered an approach to waste minimization by some states but not by others, and thus is not addressed in this guide.

A Waste Minimization Opportunity Assessment (WMOA), sometimes called a waste minimization audit, is a systematic procedure for identifying ways to reduce or eliminate waste. The steps involved in conducting a waste minimization assessment are outlined in Figure 1 and presented in more detail in the next paragraphs. Briefly, the assessment consists of a careful review of a plant's operations and waste streams and the selection of specific areas to assess. After a particular waste stream or area is established

**Figure 1. The Waste Minimization Assessment Procedure**



as the WMOA focus, a number of options with the potential to minimize waste are developed and screened. The technical and economic feasibility of the selected options are then evaluated. Finally, the most promising options are selected for implementation.

To determine whether a WMOA would be useful in your circumstances, you should first read this section describing the aims and essentials of the WMOA process. For more detailed information on conducting a WMOA, consult *The Waste Minimization Opportunity Assessment Manual*.

The four phases of a waste minimization opportunity assessment are:

- Planning and organization
- Assessment phase
- Feasibility analysis phase
- Implementation

## PLANNING AND ORGANIZATION

Essential elements of planning and organization for a waste minimization program are: getting management commitment for the program; setting waste minimization goals; and organizing an assessment program task force.

## ASSESSMENT PHASE

The assessment phase involves a number of steps:

- Collect process and facility data
- Prioritize and select assessment targets
- Select assessment team
- Review data and inspect site
- Generate options
- Screen and select options for feasibility study

*Collect process and facility data.* The waste streams at a facility should be identified and characterized. Information about waste streams may be available on hazardous waste manifests, National Pollutant Discharge Elimination System (NPDES) reports, routine sampling programs and other sources.

Developing a basic understanding of the processes that generate waste at a facility is essential to the WMOA process. Flow diagrams should be prepared to identify the quantity, types and rates of waste generating processes. Also, preparing material balances for various processes can be useful in tracking various process components and identifying losses or emissions that may have been

unaccounted for previously.

*Prioritize and select assessment targets.* Ideally, all waste streams in a facility should be evaluated for potential waste minimization opportunities. With limited resources, however, a plant manager may need to concentrate waste minimization efforts in a specific area. Such considerations as quantity of waste, hazardous properties of the waste, regulations, safety of employees, economics, and other characteristics need to be evaluated in selecting a target stream.

*Select assessment team.* The team should include people with direct responsibility and knowledge of the particular waste stream or area of the plant.

*Review data and inspect site.* The assessment team evaluates process data in advance of the inspection. The inspection should follow the target process from the point where raw materials enter the facility to the points where products and wastes leave. The team should identify the suspected sources of waste. This may include the production process; maintenance operations; and storage areas for raw materials, finished product, and work in progress. The inspection may result in the formation of preliminary conclusions about waste minimization opportunities. Full confirmation of these conclusions may require additional data collection, analysis, and/or site visits.

*Generate options.* The objective of this step is to generate a comprehensive set of waste minimization options for further consideration. Since technical and economic concerns will be considered in the later feasibility step, no options are ruled out at this time. Information from the site inspection, as well as trade associations, government agencies, technical and trade reports, equipment vendors, consultants, and plant engineers and operators may serve as sources of ideas for waste minimization options.

Both source reduction and recycling options should be considered. Source reduction may be accomplished through:

- Good operating practices
- Technology changes
- Input material changes
- Product changes

Recycling includes:

- Use and reuse of waste
- Reclamation

*Screen and select options for further study.* This screening process is intended to select the most promising options for full technical and economic feasibility study. Through either an informal review or a quantitative decision-making process, options that appear marginal, impractical or inferior are eliminated from consideration.

#### **FEASIBILITY ANALYSIS**

An option must be shown to be technically and economically feasible in order to merit serious consideration for adoption at a facility. A technical evaluation determines whether a proposed option will work in a specific application. Both process and equipment changes need to be assessed for their overall effects on waste quantity and product quality. Also, any new products developed through process and/or raw material changes need to be tested for market acceptance.

An economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment, and net present value. As in any project, the cost elements of a waste minimization project can be broken down into capital costs and economic costs. Savings and changes in revenue also need to be considered.

#### **IMPLEMENTATION**

An option that passes both technical and economic feasibility reviews should then be implemented at a facility. It is then up to the WMOA team, with management support, to continue the process of tracking wastes and identifying opportunities for waste minimization, throughout a facility and by way of periodic reassessments. Either such ongoing reassessments or an initial investigation of waste minimization opportunities can be conducted using this manual.

## SECTION 2

### FABRICATED METAL INDUSTRY PROFILE

#### Industry Description

Fabricated metal products are classified under Standard Industrial Classification (SIC) 34, and include industries engaged in processes that machine, treat, coat, plate, paint and clean metal parts. There are two major segments of the industry: job shops that process materials owned by other parties on a contractual basis, and captive shops that are owned and part of larger manufacturing facilities. Metal fabrication processes are integral parts of aerospace, electronic, defense, automotive, furniture, domestic appliance, and many other industries. Fabricated metal processes generate various hazardous waste streams, including oily wastes from machining operations, heavy metal-bearing streams from surface treatment and plating operations, and solvents, alkaline and acid solutions from metal cleaning and stripping operations, and additional wastes related to paint application. Each of the major waste generating processes is profiled below.

#### Machining Operations

Machining operations involve various metal cutting processes that include:

- turning
- drilling
- milling
- reaming
- threading
- broaching
- grinding
- polishing
- planing
- cutting and shaping

Machining processes use cutting tools of some sort that travel along the surface of the workpiece, shearing away the metal ahead of it. Most of the power consumed in cutting is transformed into heat, the major portion of which is carried away by the metal chips, while the remainder

is divided between the tool and workpiece. Interface temperatures of up to 200°F have been measured (Baumeister 1967).

*Turning processes* and some *drilling* are done on lathes, which hold and rapidly spin the workpiece against the edge of the cutting tool. *Drilling* machines are intended not only for making holes, but for *reaming* (enlarging or finishing) existing holes. This process is also carried out by reaming machines using multiple cutting edge tools. *Milling* machines also use multiple edge cutters, in contrast with the single point tools of a lathe. While drilling cuts a circular hole, milling can cut unusual or irregular shapes into the workpiece.

*Broaching* is a process whereby internal surfaces such as holes of circular, square or irregular shapes, or external surfaces like keyways are finished. A many-toothed cutting tool called a broach is used in this process. The broach's teeth are graded in size in such a way that each one cuts a small chip from the workpiece as the tool is pushed or pulled either past the workpiece surface, or through a leader hole (Baumeister 1967). Broaching of round holes often gives greater accuracy and better finish than reaming.

#### METALWORKING FLUIDS

Metalworking fluids are those liquids (or sometimes gases) that are applied to the workpiece and cutting tool in order to facilitate the cutting operation. A metalworking fluid is used:

- 1) to keep tool temperature down, preventing premature wear and damage;
- 2) to keep workpiece temperature down, preventing it from being machined to a warped shape or within inaccurate dimensions;
- 3) to provide a good finish on the workpiece;
- 4) to wash away chips; and
- 5) to inhibit corrosion or surface oxidation of the workpiece.

Also, and very important, metalworking fluids are frequently used to lubricate the tool-workpiece interface, in addition to simply cooling it.

Metalworking fluids can be air-blasted, sprayed or drawn through suction onto the tool-workpiece interface. Types of fluids include water (either plain or containing an alkali); emulsions of a soluble oil or paste; and "straight" oils (those that are not water-based) such as mineral, sulphurized, or chlorinated oil.

*Air drafts* are often used with grinding, polishing and boring operations to remove dust and chips, and to cool to a certain extent. *Aqueous solutions* containing approximately one percent by weight of an alkali such as borax, sodium carbonate or trisodium phosphate exhibit high cooling properties and also provide corrosion prevention for some materials. These solutions are inexpensive and sometimes are used for grinding, drilling, sawing, and light milling and turning operations (Baumeister 1967).

*Emulsions* consist of a suspension of oil or paste in water, typically at the ratio of one part oil to 10 to 100 parts water, depending on the application. Rich mixtures of oil to water are used for broaching, threading and gear cutting, while a 1:20 ratio suffices for most lathe work, drilling and screw machine work.

*Oil* are used for metal cutting where lubrication rather than cooling is essential for tool life and/or work quality.

## WASTE STREAMS

The major wastes from machining operations are spoiled or contaminated metalworking fluids which are treated as hazardous wastes because of their oil content, as well as other chemical additives that some contain such as chlorine, sulfur and phosphorus compounds, phenols, creosols and alkalies. While fresh metalworking fluids contain varying degrees of oil depending on their function, "tramp" hydraulic and lubricating oils also find their way into the fluids during the course of operations. Spent metalworking fluids are at present either disposed of or recycled on- or off-site. Recycling typically consists of separating the oils through such methods as centrifuging and refining them or using them as fuel.

Solvent wastes resulting from cleaning of parts and equipment also comprise a sizable waste stream. This stream is examined in the "Metal Parts Cleaning and Stripping" section.

Many fabricated metal industries generate cuttings and other scrap metal. Scrap that is destined for reclamation is not regulated as hazardous waste. If metal chips from machining operations are mixed with hazardous metalworking fluid wastes, however, the waste stream is treated as hazardous.

While metalworking fluid purchases typically account for less than 0.5 percent of the cost of operating a machine tool (Schaffer 1978), the problems that contaminated and degraded fluids can cause can be expensive and troublesome. Proper coolant and cutting oil maintenance is necessary to prevent excessive machine tool downtime, corrosion, and rancidity problems.

Metalworking fluid rancidity, perhaps the most common problem, can affect productivity and operator morale. Rancidity odors are produced in contaminated fluids due to bacterial action. The odors are especially strong when machines are started up after periods of downtime. The odors are frequently unpleasant enough that the fluid must be changed.

Insufficient maintenance of cutting fluids, especially water-based fluids, can result in workpiece and machine tool corrosion. Many cutting fluids are relied upon to protect in-process parts from corrosion, but they will not offer this protection if they have deteriorated due to rancidity, or if they are not maintained at the recommended concentrations. Cutting fluids also must not be allowed to penetrate into gear boxes or into lubricating oil reservoirs, or internal damage to machines can result.

Contamination of water miscible metalworking fluids by "tramp" lubricating and hydraulic oils constitutes one of the major causes of fluid deterioration. The tramp oils interfere with the cooling effect of the fluids, promote bacterial growth, and contribute to oil mist and smoke in the shop environment. Tramp oils impair the filterability of metalworking fluids through both disposable and permanent media filters, and thus inhibit recycling. Tramp oils also contribute to unwanted residues on cutting tools and machine parts (Sluhan, W. A.)

The most serious problem caused by tramp oils is the promotion of bacterial growth, primarily *Pseudomonas oleovorans*, in the metalworking fluid. Such bacteria degrade lubricants, emulsifiers and corrosion inhibitors in the metalworking fluids, and liberate gases, acids and salts as byproducts of their growth (Sluhan, W.A.). Bacterial growth also interferes with the cooling effect of metalworking fluids.

The tramp oils that most contribute to bacteria growth are hydraulic oils (used in hydraulic assist systems), due to their high water miscibility compared to lubricating oils, and to the phosphorus antiwear compounds they contain, which catalyze microbe growth. Lubricating and machine ramp oils create less problems, because their lower miscibility causes them to float to the surface of the coolant.

## Metal Parts Cleaning And Stripping

Cleaning and stripping operations are integral to numerous processes in industries involved with the manufacture of metal parts and equipment. Virtually all fabricated metal objects require some form of cleaning. Machined parts are cleaned with solvents; paint, oxidation and old plating is stripped from workpieces using caustics and abrasives; and workpieces in plating lines are cleaned several times using water, acids, caustics and detergents. Implementation of proper, environmentally sound cleaning and stripping techniques will markedly reduce toxicities and volumes of wastewater, as well as reducing process chemical requirements.

### PROCESS DESCRIPTION

Five types of metal cleaning media are utilized by industry: 1) solvents (both halogenated and nonhalogenated); 2) alkaline cleaners; 3) acid cleaners; 4) nonchemical, abrasive materials; and 5) water. Alkaline and acid cleaners are usually referred to as aqueous cleaners. Mixtures of solvents and alkalines are frequently used. Mixtures where water-immiscible solvent is emulsified in water (often containing other additives) are termed emulsion cleaners.

Although metal parts cleaning is frequently thought of as a simple operation requiring little more than washing a part in solvent, many metal parts require sophisticated and rather complex sequences of cleaning steps. The design of a cleaning operation is generally dependent upon three interrelated factors:

- *The nature of the contamination.* It is important to know the composition as well as the history of contaminants on the metal's surface, in order to design the proper cleaning system and sequence of baths or other operations. Alkaline cleaners are often used to remove heavy soils and some solid oils, while caustics are good paint stripping agents. Acid cleaners and abrasives are employed to remove oxidation scale and rust. When parts have been contaminated with several materials, sequencing of cleaning operations can be important. For instance, a layer of oily contamination might be removed by an alkaline cleaner before abrasives are used to remove a rust layer.
- *The metal substrate.* The contaminant must be removed to the required degree without adversely affecting the metal substrate. Reactivity of different metals with alkaline and acids varies, and thus cleaners that are

appropriate for one metal may not be for another.

- *The degree of cleanliness required.* The cleaning that a metal surface requires varies depending upon the particular surface treatment, plating or coating operations it will be subjected to. For instance, parts going to a cyanide-zinc plating bath do not usually need to first receive a high level of cleaning since cyanide-based plating solutions exhibit strong cleaning actions of their own. For a nickel plate to adhere to a metal surface, on the other hand, the surface must be extremely clean. Thus, thorough and rigorous cleaning operations are needed prior to the nickel plating.

It is frequently the case that no one cleaning operation can be specified as best based simply on reviewing the above factors. Several cleaning methods often appear appropriate, and only through experiment can the best one be selected.

Cleaners, except for abrasives, are normally contained in large open tanks, with the parts to be cleaned mounted on racks or in perforated horizontal barrels. The decision to use racks or barrels depends on the size and shape of the part as well as the type of coating it requires.

### SOLVENT CLEANING

Solvents are the most widely used class of cleaners. They are employed for removing oil-based contaminants, in either cold cleaning, dipphase cleaning, or vapor phase cleaning operations.

Cold cleaning generally employs unheated or slightly heated nonhalogenated solvents, and is the most common type of cleaning. The four categories of cold cleaning are: 1) wipe cleaning; 2) soak cleaning; 3) ultrasonic cleaning; and 4) steam gun stripping. Wipe cleaning consists of soaking a rag in solvent and wiping the metal part clean. Soak cleaning involves the immersion of the parts in a solvent tank. Ultrasonic cleaning is identical to soak cleaning, except that an ultrasonic unit is added to the tank, which provides a vigorous cleaning action throughout the tank. The main application of steam gun stripping is for paint removal from metal objects. A stripper made up of nonhalogenated solvents is fed into a steam line, through an adjustable valve, mixed with the steam and ejected at high speed from a nozzle.

Diphase cleaning systems are so named because they use both water and solvent phases for cleaning. Parts to be cleaned first pass through a water bath, then a solvent spray. Vapor phase cleaning, also called vapor degreasing, consists of a tank of halogenated solvent heated to its boiling point. Parts to be cleaned are placed in the vapor

zone above the liquid solvent. The vapor that condenses on the cooler part dissolves oil-based contamination and rinses the part clean. Since the potential exists for considerably greater air emissions from vapor phase cleaning than from cold cleaning tanks, special recovery equipment is installed, consisting of cooling jackets and/or finned coil condensers. By cooling the air above the vapor, a dense cool air blanket is formed which helps suppress vapor from escaping. The second unit, a finned coil condenser, is installed inside the tank and condenses any vapor that reaches it.

### **AQUEOUS (ALKALINE AND ACID) CLEANING AND STRIPPING**

The cleaning action of aqueous cleaners relies mainly on displacement of soils rather than on their dissolution, as is the case with organic solvent. Since both alkaline and acid aqueous cleaners and strippers use the same equipment, they are discussed together. Alkaline cleaning solutions contain builders (sodium salts of phosphates, carbonates, silicates, and hydroxides) and surfactants (detergents and soaps). Other additives may include anti-oxidants and stabilizers as well as small amount of solvents. Alkaline cleaners and strippers are employed to remove soil from metal parts, as well as old plating and paint. Acidic cleaning solutions may contain mineral acids (nitric, sulfuric and hydrochloric), organic acids (sulfamic, acetic, oxalic or cresylic), detergents, chelating agents and occasionally small amount of solvents. Acid cleaners remove rust, scale, and "smut", which is formed from electrocleaning. Very strong alkaline cleaners containing cyanide and cleaning agents have recently been formulated to replace acid cleaners. No matter what type of aqueous cleaner is used, soak tanks similar to those used for solvents are the most common cleaning method employed. Some aqueous cleaners, however, are used in electrochemical cleaning, in which the workpiece is connected to a source of current. In direct current electrochemical cleaning, the workpiece is attached to the cathode, causing hydrogen gas to be formed at the part's surface that provides a scrubbing action. Smut formation (the plating of metal contaminants in the solution onto the workpiece) does sometimes occur, however, as well as hydrogen embrittlement of the metal. These disadvantages are avoided in reverse current cleaning, or electropolishing, in which the workpiece is attached to the anode. Metal substrate is dissolved electrolytically, liberating the surface contaminant.

### **ABRASIVE CLEANING AND STRIPPING**

Abrasive cleaners are designed for removing rust, oxides and burrs, old plating and paint, and to create a smooth surface. Typical abrasives are aluminum oxide or silicon carbide mixed with an oil or water based binder. The abrasive-binder mixture is applied to a buffing wheel made from an absorbent material such as cloth. The metal

part is held against the spinning wheel. Vibratory finishing is another method of abrasive cleaning in which a load of metal parts is immersed in a vibrating tank containing abrasive material and water. Similar cleaning methods employ tumbling barrels and centrifugal barrel finishing.

### **WATER CLEANING**

Water cleaning is an integral part of every parts cleaning process. Most of the cleaning operations mentioned above require that a water wash be performed before and after each operation. The washing is generally done either in a soak tank, or using a spray unit. Because rinse water generally comprises the largest waste stream in metal fabrication processes, measures for reducing the amount of water required (such as extending water bath life by preventing its contamination by other cleaning media) are very important in reducing the overall volume of wastes.

### **WASTE STREAMS**

The primary wastes associated with metal parts cleaning are listed in Table 1, along with their sources. The composition of the waste depends on the cleaning media used, type of substrate, and the type of soil removed (oils, greases, waxes, metallic particles, oxides, etc.). If a facility has a wastewater treatment system, primary rinse water, alkaline and acid cleaning solutions can be mixed together (one acts to neutralize the other) and then treated.

Secondary rinse water (if secondary rinse is employed) is usually used to replace discarded primary rinse water and/or used as a makeup for cleaning solutions. For facilities using small amounts of cleaner, the tendency is to drum the material for disposal. Solvent waste can be sent to an off-site recycler or recycled on-site using distillation equipment.

### **Metal Surface Treatment And Plating Operations**

Metal surface treatment and plating are practiced by most industries engaged in forming and finishing metal products, and involve the alteration of the metal workpiece's surface properties, in order to increase corrosion or abrasion resistance, alter appearance, or in some other way enhance the utility of the product. Plating and surface treatment operations are typically batch operations, in which metal objects are dipped into and then removed from baths containing various reagents for achieving the required surface condition. The processes involve moving the object to be coated (the workpiece) through a series of baths designed to produce the desired end product. Workpieces can be carried on racks or in barrels. Large workpieces are mounted on racks that carry the parts from bath to bath. A set of small parts can be contained in barrels that rotate in the plating bath.



**Table 1. Metal Parts Cleaning Wastes**

No.	Waste Description	Process Origin	Composition
1.	Abrasive	Removal of rust, scale polishing of metal	Aluminum oxide, silica metal, water, grease
2.	Solvents	Removal of oil-based soils	Halogenated and non-halogenated solvents, oil-based contaminants
3.	Alkalines	Removal of organic soils, descaling	Alkaline salts, additives, organic soils, water
4.	Acids	Removal of scale, smut	Acids, additives, dissolved metal salt, water
5.	Rinse water	Removal of previous cleaning material	Water with traces of cleaners and additives

## PROCESS DESCRIPTION

Plating operations can be categorized as electroplating and electroless plating processes. Surface treatment includes chemical and electrochemical conversion, case hardening, metallic coating, and chemical coating. Most metal surface treatment and plating processes have three basic steps: surface cleaning or preparation (which was examined in the previous action); the actual modification of the surface, involving some change in its properties (e.g. case hardening, or the application of a metal layer); and rinsing or other workpiece finishing operations.

### *Chemical and Electrochemical Conversion*

Chemical and electrochemical conversion treatments are designed to deposit a coating on a metal surface that performs a corrosion protection and/or decorative function, and in some instances is a preparation for painting. Processes include phosphating, chromating, anodizing, passivation, and metal coloring. Phosphating treatments provide a coating of insoluble metal phosphate crystals that adhere strongly to the base metal. The coatings provide some corrosion resistance, but their main function, due to their absorptivity, is as a base for the adhesion of paints, lacquers, and oils to the metal surface. Chromate coatings are applied to minimize rust formation and to guarantee paint adhesion. Chromating baths' ingredients include hexavalent chromium, one or two mineral acids (e.g. sulfuric or nitric), and often several organic or inorganic activating compounds.

Anodizing employs electrochemical means to develop a surface oxide film on the workpiece, enhancing its corrosion resistance. Passivation is a process by which

protective films are formed through immersion in an acid solution. In stainless steel passivation, embedded ion particles are dissolved and a thin oxide coat is formed by immersion in nitric acid, sometimes containing sodium dichromate.

### *Case Hardening*

Case hardening produces a hard surface (the case) over a metal core that remains relatively soft. The case is wear-resistant and durable, while the core is left strong and ductile. Case hardening methodologies include carburizing, carbonitriding, nitriding, microcasing, and hardening using localized heating and quenching operations.

Carburizing, the most widely used case hardening operation, involves diffusion of carbon into a steel surface at temperatures of 845° to 955°C, producing a hard case in the high carbon areas. Nitriding processes diffuse nascent nitrogen into a steel surface to produce case-hardening. Nitriding is accomplished using either a nitrogenous gas, (usually ammonia), or a liquid salt bath, typically consisting of 60 to 70 percent sodium salts, mainly sodium cyanide, and 30 to 40 percent potassium salts, mainly potassium cyanide. Carbonitriding and cyaniding involves the diffusion of both carbon and nitrogen simultaneously into a steel surface.

Applied energy methods are those that generate a case through localized heat and quenching, rather than through use of chemicals. Very rapid heat application results in surface hardening with little heat conducted inward. Since no carbon or nitrogen is diffused into the workpiece, it is the existing carbon content of the ferrous metal that

determines hardness response. Heating can be accomplished through electromagnetic induction, high temperature flames or high velocity combustion product gases.

### **Metallic Coatings**

Metallic coatings provide a layer that changes the surface properties of the workpiece to those of the metal being applied. The workpiece becomes a composite material with properties generally not achievable by either material singly. The coating's function is usually as a durable, corrosion resistant protective layer, while the core material provides the load-bearing function. Metallic coatings as defined here refer to diffusion coatings (in which the base metal is brought into contact with the coating metal at elevated temperatures allowing lattice interdiffusion of the two materials); spraying techniques; cladding (application using mechanical techniques); vapor deposition and vacuum coating.

Hot dipping is a diffusion process that involves partial or complete immersion of the workpiece in a molten metal bath. Common coating materials include aluminum, coated lead, tin, zinc, and combinations of the above. The coating metal in a cementation diffusion process is applied in powdered form at a high temperature (800 to 1100°C), in a mixture with inert particles such as alumina or sand, and a halide activator. The main applications of sprayed diffusion coatings are for workpieces difficult to coat by other means due to their size and shape, or that are damageable by the high temperature heating required of other methods. Vapor deposition and vacuum coating produce high quality, pure metallic layers, and can sometimes be used in place of plating processes. A layer of metal cladding can be bonded to the workpiece using high pressure welding or casting techniques. Cladding can offer an alternative to plating in some situations.

### **Electroplating**

Electroplating is achieved by passing an electric current through a solution containing dissolved metal ions as well as the metal object to be plated. The metal object acts as a cathode in an electrochemical cell, attracting metal ions from the solution. Ferrous and nonferrous metal objects are typically electroplated with aluminum, brass, bronze, cadmium, chromium, copper, iron, lead, nickel, tin, and zinc, as well as precious metals such as gold, platinum, and silver. Common electroplating bath solutions are listed in Table 2.

The sequence of unit operations in an electroplating operation is very similar when either racks or barrels are used to carry parts. A typical sequence involves various types of cleaning steps, stripping of old plating or paint, the actual electroplating steps, and rinsing steps between and after each of the above operations.

**Table 2. Common Electroplating Bath Compositions**

Electroplating Bath Name	Composition
Brass and Bronze	Copper cyanide Zinc cyanide Sodium cyanide Sodium carbonate Ammonia Rochelle salt
Cadmium Cyanide	Cadmium cyanide Cadmium oxide Sodium cyanide Sodium hydroxide
Cadmium Fluoroborate	Cadmium fluoroborate Fluoroboric acid Boric acid Ammonium fluoroborate Licorice
Copper Cyanide	Copper cyanide Sodium cyanide Sodium carbonate Sodium hydroxide Rochelle salt
Copper Fluoroborate	Copper fluoroborate Fluoroboric acid
Acid Copper Sulfate	Copper sulfate Sulfuric acid
Copper Pyrophosphate	Copper pyrophosphate Potassium hydroxide Ammonia
Fluoride-Modified Copper Cyanide	Copper cyanide Potassium cyanide Potassium fluoride
Chromium	Chromic acid Sulfuric acid
Chromium with Fluoride Catalyst	Chromic acid Sulfate Fluoride

Electroless plating uses similar steps, but involves the deposition of metal on a metallic or non-metallic surface without the use of external electrical energy.

### **WASTE STREAMS**

Common plating and surface treatment process wastes are listed in Table 3. Two of the waste streams, *spent alkaline cleaning solutions* and *spent acid cleaning solutions*, are generated by periodic replacement of contaminated solutions. *Rinse waters* are generated from overflow of rinse tanks and contamination by drag-out from cleaning baths. Waste removed from plating tanks by the continuous filtering of the baths results in *filter sludges*.

**Table 3. Process Wastes**

Waste Description	Process Origin	Composition
Spent process solutions	Plating and chemical conversion	See Table 2.2
Filter sludges	Plating and chemical conversion	Silica, silicides, carbides, ash, plating bath constituents
Quench oils and quench oil tank cleanup wastes	Case hardening	Oils, metal fines, combustion products
Spent salt bath	Carburizing, nitriding, cyaniding	Sodium cyanide and cyanate. Potassium cyanide and cyanate.
Wastewater treatment sludge	Wastewater treatment	Metal hydroxides, sulfides, carbonates
Vent scrubber wastes	Vent scrubbing	Similar to process solution composition
Ion exchange resin reagents	Demineralization of process water	Brine, HCl, NaOH

Wastes produced at a particular facility will be similar to those listed, but their precise composition will depend on the specific process. Some or all of the waste types listed may be combined into a single stream before treatment and disposal. It is common to combine concentrated cyanide wastes from plating and cleaning solutions, for instance, with filter sludges. These are generally kept separate, however, from acidic wastes and from the dilute cyanide solutions.

On a volume basis, contaminated rinsewater accounts for the majority of plating process waste. As shown in the previous sections, plating processes can involve many rinsing steps. Rinsewater is used to wash off the drag-out from a workpiece after it is removed from a bath. *Drag-out* refers to the excess solution that adheres to the workpiece surface and gets carried out of the solution bath upon withdrawal of the workpiece from the bath. In general, the use of small part barrels in the plating process (barrel plating) produces more drag-out than rack plating. This is because a barrel carries in it more plating solution upon withdrawal from the bath than a rack does, and because drainage of the drag-out back into the bath is more difficult with barrels. If the drag-out from one bath is carried into the next bath in the sequence due to incomplete rinsing, it is referred to as "drag-in," and is considered a contaminant in the latter bath.

Spent cleaning and plating solutions are another source of plating wastes. Several types of cleaning solutions are used to prepare a metal surface for electroplating. Stripping

wastes are a special type of cleaning waste. They result from the stripping off of the old plated deposit prior to the deposition of a new metal plate. Cleaning solutions may be acidic or basic, and may contain organics. Heavy metals are usually not present, although some cleaning solutions contain cyanide. Spent plating solutions contain high concentrations of metals. These solutions are not regularly discarded like cleaning solutions, but may require purging if impurities build up.

Wastes produced from spills and leaks are usually present to some extent in an electroplating process. Water is used to wash away floor spills, and the resulting wastewater contains all of the contaminants present in the original solutions. Wastewater is also produced from the wet scrubbing of ventilation exhaust air.

Wastewater produced in an electroplating process may contain a variety of heavy metals and cyanide. The metals are typically removed by adding lime or other precipitating agents, and precipitated under alkaline pH. The resulting metal hydroxide precipitate forms a dilute sludge, which is thickened and then disposed of by landfilling.

### Paint Application

The application of paint is practiced within most fabricated metal industries. Surface coatings are used wherever it is desired to provide decoration, protection, and/or safety marking to a product or item. Most paint coatings for fabricated metal products are solvent based

although many shops are replacing these with water based materials.

## PROCESS DESCRIPTION

Before a product coating can be applied to a surface, the surface must be free from contamination. As described above, many different types of abrasives, alkalines, acids, and solvents, as well as water, are used by industry to clean metal surfaces. Once a part is cleaned, surface treatment such as phosphate coating can be applied if desired. The purpose of surface treatment is to condition or prepare the surface so that the paint forms a better bond with the metal surface.

After the item has been cleaned and treated, paint can be applied. Depending on the size, shape, complexity, and quantity of items to be painted, different application methods can be employed. When it is desired to paint a large number of very small items, the most commonly used methods are *tumbling, barreling, or centrifuging*. For all three methods, the parts are placed inside a barrel, solvent-based paint is poured onto the items, and the barrel is then rotated. After a short time and at the correct point of tackiness, the parts are transferred to an oven in a wire basket. While paint consumption using these methods is very small, the empirical nature of the operation requires that the operator be highly experienced to achieve reliable results.

For cylindrical items, a commonly used method is *dipping*. Here the paint is held in a large tank and the object to be painted is slowly lowered into the tank and then withdrawn. Many complex items can be dip painted provided that the drainage points (the places where the excess paint drips off), can be located where they are not noticeable.

*Flow coating* is often employed for items that would be difficult to dip because of their size or shape, or as a means of avoiding the installation and operation of large dip tanks. A flow coating system operates by using high pressure sprays to flood the item with solvent-based paint. After spraying, the item is allowed to drain and the excess paint is recirculated. Since a considerable amount of bubbling occurs due to spraying, the item is then passed through a solvent chamber where the solvent vapors allow the paint to reflow. Following this operation, the item is then oven-dried. The main disadvantage of flow coating is high solvent loss, which can be three times as large as for dipping and twice as great as for spraying.

For relatively flat items of large area, *roller coating* and *curtain coating* machines are used. Roller coating is used extensively by the canning industry for painting flat

metal sheets that are then fabricated into cans. It is also used for spreading or applying glue to wood in the manufacturing of plywood. A roller coating machine operates by metering paint or coating material onto a roller and then transporting the item past the roller by means of a conveyor belt. A curtain coating machine consists of a pressurized container along the bottom of which is an adjustable slit that allows the coating to flow and form a vertical curtain. A conveyor belt is placed on each side of the curtain so that work items are passed through the curtain and coated without the conveyor belts being coated.

While all of the above-mentioned methods have found widespread acceptance by industry, the most widely used method for applying paint is still the spray gun. A spray gun operates by using compressed air, to atomize the paint and produce a fan or circular cone spray pattern. Many installations are automated so that a fixed gun is turned on when an object passes in front of it. In its simplest use, the gun is hand-held and the object remains stationary. Some of the variations on spray gun painting are airless spray guns and electrostatic spray guns. Airless spray guns force the paint out at high pressure so that air is not required for atomization. By eliminating the use of compressed air, operating costs are lower, spray mists are not produced, and expensive exhaust systems are not required. Electrostatic spray units are designed so that the atomized paint leaving the gun has a positive charge. This positive charge causes the paint to be attracted to the object which is connected to ground. Since more of the paint reaches its target (thereby reducing overspray), less waste is generated.

Following the application of paint, the item is passed through a drying or curing oven. The curing methods employed, infrared or ultraviolet, will depend on the type of paints being used. Once dried, the items are sent to inspection and final packaging or assembly. If a part fails inspection because of a bad finish, it is usually reworked by stripping off the paint and returning it to the cleaning operation.

## WASTE STREAMS

The primary wastes associated with product coating applications consist of empty paint containers, spent cleaning solutions, paint overspray (including paint collected by air pollution control equipment), spent stripping solutions, and equipment cleaning wastes. Waste minimization methods for stripping and cleaning are examined under the "Parts Cleaning" heading in Section Three; source reduction and recycling methods for the other waste streams are examined under "Paint Wastes" in Section Three.

# SECTION 3

## WASTE MINIMIZATION OPTIONS

### FOR FABRICATED METAL PRODUCT FACILITIES

#### Introduction

The list of individual primary fabricated metal industry waste streams and their sources along with a list of source reduction and recycling methods is presented in Table 4. Recommended waste reduction methods and identified procedures are discussed in the following sections. These methods came from industry contacts and published accounts in the open literature.

In addition to the waste reduction measures that are classified as process changes or material/product substitutions, a variety of waste reducing measures labeled as "good operating practices" has also been included. Good operating practices are defined as procedures or institutional policies that result in a reduction of waste. The following describes the scope of good operating practices:

- Waste stream segregation
- Personnel practices
  - Management initiatives
  - Employee training
- Procedural measures
  - Documentation
  - Material handling and storage
  - Material tracking and inventory control
  - Scheduling
- Loss prevention practices
  - Spill prevention
  - Preventive maintenance
  - Emergency preparedness

Good operating practices apply to all waste streams.

#### Material Handling And Storage

Improper storage and handling can result in spoilage and obsolescence of raw materials, resulting in the generation of hazardous and other waste streams. Efficient

operating practices can reduce or eliminate waste resulting from obsolescence and improper storage. Source reduction methods for reducing waste include:

#### *Material Preinspection*

Materials should be inspected before being accepted and unacceptable or damaged materials returned to the manufacturer or supplier. This avoids both disposal of a nearly full container of unusable material and printing an unacceptable product.

#### *Proper Storage of Materials*

Many chemicals are sensitive to temperature and humidity. Much waste can result from improper storage. Chemical containers list the recommended storage conditions. Meeting the recommended conditions will increase their shelf life.

#### *Restrict Traffic through Storage Area*

To prevent raw material contamination, the storage area should be kept clean. Also, the storage area should not be open to through traffic. Through traffic will increase dust and dirt in the storage area, increasing possible contamination. In addition, spills in the storage area will be easier to contain if traffic is restricted.

#### *Inventory Control*

Inventories should be kept using the "first-in, first-out" practice. This will reduce the possibility of expired shelf life. This practice may not work for specialty materials that are seldom used. Computerized inventory systems can track the amounts and ages of the raw materials.

#### *Purchase Quantities According to Needs*

Raw material order quantities should be matched to usage. This avoids having a large, partly used container of ink going bad in storage because it wasn't properly sealed. Large shops should order materials in large containers, which may be returnable, thereby eliminating or reducing the need to clean them. It takes less time to scrape out the large single container than several small ones. Ordering materials in returnable tote bins may maximize these advantages.

**Table 4. Waste Minimization Methods for Fabricated Metal Industry Processes**

Process	Waste Stream	Source Reduction Options	Recycling Options
Material Handling and Storage		Material Preinspection Proper Storage of Materials Restrict Traffic through Storage Area Inventory Control Purchase Quantities According to Needs	Test Expired Material Usefulness
Machining Wastes	Metalworking Fluid	Use of High Quality Metalworking Fluid Demineralized Water Use Concentration Control Sump and Machine Cleaning Gasket, Wiper and Seal Maintenance Cleaning of Metalworking Fluid Assigning Fluid Control Responsibility	Filtration of Metalworking Fluids Skimming Coalescing Hydrocycloning Centrifuging Pasteurization Downgrading
Parts Cleaning	Solvents	Tank Lid Installation Increase in Freeboard Space Installation of Freeboard Chillers Cross-Contamination Avoidance Appropriate Makeup Solutions Solvent Standardization Consolidating Operations Media Substitution	Gravity Separation Filtration Batch Distillation Fractional Distillation Use as Fuel On- and off-site Recycling
	Aqueous Cleaners	Sludge Removal Use of Dry Cleaning and Stripping Methods Media Substitution	Oil Separation Pickling Bath Recycling
	Abrasives	Use of Greaseless or Water-Based Binders Use of Liquid Sprays Water Level Control Synthetic Abrasives	
	Rinsewater	Rack and Barrel System Design Rinse System Design Spray and Fog Rinses Chemical Rinsing Deionized Water	
Surface Treatment and Plating	Process Solutions	Increasing Solution Life Material Substitution Process Substitution Chemical Coating Mechanical Cladding and Coating	Use of Cleaning Baths as pH Adjusters Metal Recovery Evaporation Reverse Osmosis Ion Exchange Electrolytic Recovery Electrodialysis
	Rinsewater	Reduction in Drag-Out of Process Chemicals: Speed of Withdrawal Surface Treatment Plating Bath Concentrations	Rinsewater Reuse

**Table 4. Waste Minimization Methods for Fabricated Metal Industry Processes (cont'd)**

Process	Waste Stream	Source Reduction Options	Recycling Options
		Surfactant Use Solution Temperature Workpiece Positioning Drag-Out Recovery System Design Considerations: Rinsetank Design Multiple Rinsing Tanks Reactive Rinsing Fog Nozzles and Sprays Automatic Flow Controls Rinse Bath Agitation	
Surface Treatment and Plating (cont'd)	Treatment Wastes	Precipitating Agents and Other Treatment Chemicals Trivalent Chromium Use Waste Segregation Sludge Dewatering	
	Case Hardening Wastes	Selection of Clean Processes	
Paint Application	Empty Containers	Waste Segregation Bulk Purchasing Minimizing Residuals	
	Paint Application Waste	Overspray Reduction: Equipment Modifications Operator Training Material Substitution Replacing Solvent-Based Coatings with: Water-Based Coatings Radiation-Curable Coatings Powder Coatings	Reusing Solvent Paint Mixtures Recovery through Distillation Recovery through Filtration

### *Test Expired Material for Usefulness*

Materials having expired shelf-life should not automatically be thrown out. Instead, this material should be tested for effectiveness. The material may be usable, rather than becoming a waste. A recycling outlet should be found for left over raw material that is no longer wanted.

## **Machining Wastes**

### **SOURCE REDUCTION METHODOLOGIES**

A primary problem in metalworking fluid management is contamination with tramp oil and the problems that result from this. While the best solution for tramp oil problems is to prevent the oils from entering the metalworking fluid, some contamination will occur as the machines and their oil seals and wipers wear. This can be reduced through preventive maintenance such as periodic seal and wiper replacement. Optional metalworking fluid performance starts with a preventive maintenance program that includes:

- use of high quality, stable cutting and grinding fluids;
- use of demineralized water for mixing purposes;
- fluid concentration control;
- control of fluid chemistry (pH, dissolved oxygen, etc.);
- fluid contamination prevention;
- periodic sump and machine cleaning;
- periodic gasket, wiper and seal inspections and replacements to minimize tramp oil contamination;
- regular cleaning of metalworking fluid through filtering or centrifugation, in order to minimize microbe growth by controlling tramp oil buildup; and
- assignment of responsibility for fluid control to one person.

Fluid cleaning can be accomplished through filtration and clarification, using bag, cartridge or disc filters, chip wringers and centrifuges. Periodic addition of specialized biocides into the metal working fluid can also extend its life, by combating microbe growth (Zabik 1987; Porter 1988).

An irritating problem in many shops is the contamination of fluids with trash such as cigarette butts, food or food wrappers that find their way into sumps. Better housekeeping procedures, including operator training and coverage of sumps with screens or solid covers, can help reduce this ongoing problem.

Because water constitutes 90 to 99 percent of water soluble cutting and grinding fluids, high mineral content water can adversely affect fluid performance by deteriorating emulsions, causing corrosion and enhancing microbial growth. Purification of water through deionization or reverse osmosis before it is mixed with the fluid can help reduce these problems.

It is important to carefully select the metalworking fluid most suitable for the particular application, in order to maximize performance and long fluid life. Fluid selection should be done from an overall, plant-wide perspective, in order to find the best products as well as to minimize the number of different fluids in use. With the broad applications of some high quality fluids, it is sometimes possible to employ only one type in an entire plant, although different applications in the plant may require different proportions of water and concentrate.

A periodic schedule of metalworking fluid testing can alert plant staff to deteriorating fluid qualities in time to prevent failure of the fluid. Tests might include analyses for pH, specific component concentration including additives, particulate matter, tramp oil, rust inhibitor, biocide concentrate, and dissolved oxygen. Low pH values indicate low product concentrations, and thus related problems such as increases in metal fines or other suspended solids, and heightened vulnerability to microbe growth and tramp oil contamination (Porter 1988).

In order to make informed choices of fluids, it is important to know not only about the fluids' cutting and grinding abilities, but also about factors such as their resistance to bacterial attack, the residues they leave on machine tools and workpieces, the corrosion protection they offer, the health dangers they present, such as skin or respiratory irritation, and the environmentally hazardous chemicals they contain. Chemically active lubricants are often used, for instance, that contain chlorine, sulfur or phosphorus (Centrico 1986). Fluids can also contain phenols, creosols and harsh alkalis. Tramp oils often carry other hazardous contaminants into metalworking fluid, and can lead to breakdown of the fluid and formation of hydrogen sulfide.

Use of synthetic metalworking fluids can sometimes result in dramatically increased fluid life. Synthetic fluids are made up of chemicals such as nitrites, nitrates, phosphates and borates. Synthetic fluids contain only zero to one percent soluble oils in the fluid concentrate, compared to 30 to 90 percent soluble oil in non-synthetic metalworking fluid concentrates. While the lubricity of synthetic fluids is lower than many non-synthetic fluids, an advantage of synthetic fluids is that tramp oils are not able to contaminate them as easily as non-synthetic fluids, for they are not able to readily enter the fluid emulsion, which leads to breakdown



of the fluid's qualities (EERC 1988). Many synthetic fluids offer greater thermal stability at high temperatures, resisting oxidation better than non-synthetic fluids.

Gases can sometimes be used in place of coolants, because they offer cooling of workpieces and tools with no workpiece contamination. Air is the most frequently used gas, and is employed both in dry cutting or with other fluids. Nitrogen and carbon dioxide are occasionally used as well, but their cost is high and therefore their applications are limited (Porter 1988).

### RECYCLING METALWORKING FLUIDS

By recycling deteriorated or contaminated fluids, costly hauling and disposal can be reduced. Also, recycling will minimize the need for purchase of high priced fluid concentrates. While many shops engage off-site recycling companies to handle their spent fluids, it is very feasible for larger shops to recycle in-house. The processes recyclers employ separate oily wastes from water. The water is released to the sewer while the oil is refined or used as fuel. In-house recycling typically has a different focus than off-site: to extend the usable life of metalworking fluids, rather than to separate and refine the oils it contains. Continuous in-house filtration of fluids in machine sumps reduces the requirements for new fluids, avoids recycler's charges, and saves money by reducing machine downtime for cleaning and coolant recharge.

Methodologies for recycling metalworking fluids include filtration, ultrafiltration for water removal, skimming, flotation, coalescing, hydrocycloning, centrifuging, pasteurization and downgrading. In gravity pressure and vacuum filtration technologies, the waste coolant is passed through a disposable filter to remove solid particles. Diatomaceous earth filters are also used at times, but their adsorptive properties are so high that they can actually remove additives from a metalworking fluid. In skimming separations, the metalworking fluid is allowed to sit motionless until immiscible tramp oil floats to the surface, where it is manually removed or skimmed automatically using oil-attracting belts, floating ropes or wheels. If the oil contaminants are fairly miscible, as is the case with hydraulic oils, or if the coolants in the fluid have emulsified the oils, they will not rise to the surface on their own, and other separation techniques must be used. Separation of oil contaminants can sometimes be enhanced through dissolved air flotation. In this method, the metalworking fluid waste stream is put under high pressure and air is injected. When the pressure is released, the air comes out of the solution, attaches to the oil and grit in the

fluid, and floats it to the surface, where it can be skimmed off.

In coalescing techniques, the fluid is brought into contact with an oleophilic ("oil loving") medium formed into a high surface area shape such as corrugated plates or vertical tubes. Oil droplets impinge on the media and cling to it, eventually coalescing to form large droplets that float to the surface of the fluid and are skimmed off by adjustable weirs. Coalescers are not effective for removing water-miscible hydraulic oils or emulsified lubricating oils, for these do not readily separate from the metalworking fluid.

A hydrocyclone uses centrifugal force to separate solid contaminants from the fluid. Waste fluid is pumped under pressure into the top of a cone-shaped compartment in which a vortex is set up. As the spinning fluid accelerates down the cone, solids are forced to the outer wall. The solids move downward and are discharged, while the clean fluid is forced by back pressure to move upward through the center of the cone. Hydrocyclones can remove particles down to about 5 microns; they cannot, however, efficiently remove small quantities of tramp oil. The advantage of this type of system is that it is mechanically very simple and relatively easy to operate.

Centrifuging involves mechanical rotation of the metalworking fluid, providing several thousand G's of separating force. Centrifugation is able to remove hydraulic oils and other emulsified tramp oils as well as "free" oils. Low RPM centrifuges are also used as "chip wringers" to separate reusable oil clinging to metal chips.

One recycling method gaining popularity is a combination of pasteurization and low speed centrifuging. While this method is promising for certain applications, pasteurization is a tremendously energy intensive process, and is only marginally successful in controlling microbe growth. *Pseudomonas aeruginosa* and *Pseudomonas oleovorans* are two coolant-attacking bacteria that are notoriously hard to kill. Pasteurization can also cause de-emulsification of oils, and if the metalworking fluid has degraded to the point where it has a gray color and emits a hydrogen sulfide odor, pasteurization and centrifugation can only remove the odor and color, but often cannot restore the fluid's lubricity and corrosion inhibition.

Used high performance hydraulic fluids that no longer fulfill exacting specifications can often be downgraded and employed as cutting oils. For instance, certain mil spec hydraulic oils cannot be employed in their original application once their viscosity has dropped due to polymer

shearing, but if the oils have been kept clean, additives can be mixed into them to make excellent metalworking fluids.

## Parts Cleaning

### SOURCE REDUCTION METHODOLOGIES

#### *Solvents*

The most common piece of equipment used for solvent cleaning is the soak tank, followed by the vapor degreaser. The main methods for reducing waste from both types of equipment are the same. The two most important source reduction goals are to minimize evaporation vapor loss and to maintain solvent quality. By reducing evaporation loss, the composition of the solvent will be maintained as close as possible to its original composition. By maintaining solvent quality, the need for replacement is reduced. Halogenated solvents contain chemical stabilizers that help prevent acid formation and remove acid contaminants from the bulk of solution. As a solvent is used, its ability to neutralize or prevent acid formation lessens. Unless measures are taken to maintain quality and prevent a solvent from "going acid," the entire quantity of solvent will have to be replaced more often. Measures that are considered helpful in maintaining quality and minimizing vapor loss include:

- Installation of tank lids
- Increase in freeboard space
- Installation of freeboard chillers
- Avoidance of cross-contamination
- Sludge removal
- Use of appropriate makeup solutions
- Solvent standardization
- Consolidating operations

Besides maintaining quality and minimizing loss, substitutions of hazardous solvents with other media is often a very effective means of source reduction. Media substitution is discussed at the end of this Source Reduction section.

*Installation of lids on tanks.* Lids should be placed on all tanks when they are not in use. By installing a cover during periods of non-use, vapor degreaser solvent loss can be reduced by 24 to 50 percent. Additional reductions have been achieved by installing covers designed to allow the bath to be used even while the cleaning operation is in progress. Known as "silhouette entries," the openings in the covers have shapes that match the shapes of the parts being degreased and therefore minimize the area for vapor loss. Covers should be designed to slide closed horizontally

across the open surface. This disturbs the vapor zone less than covers that are hinged.

*Increase in freeboard space.* Freeboard is the distance between the top of the vapor zone and the top of the tank. EPA regulations recommend a vapor degreaser freeboard of 75 percent of the tanks width. For shops where air turbulence is present, increasing the freeboard to 100 percent can provide an additional reduction. Increasing the freeboard on other tanks containing volatile solvents as well as on degreasers is effective in reducing solvent usage and solvent waste stream volumes.

*Installation of freeboard chillers in addition to cooling jackets.* In this approach, a second set of refrigerated coils is installed above the vapor degreaser's condenser coils. These coils chill the air above the vapor zone and create a secondary barrier to vapor loss. Therefore, special water collection equipment is also frequently required, due to water contamination of the solvent from frost build-up on the coils.

*Avoidance of cross-contamination* of solvent is an issue to be addressed, especially when the types of solvents being used have similar sounding names. As little as one-tenth of one percent 1,1,1-trichloroethane mixed into a tank of trichloroethylene can cause an acid condition and render the bath unusable for many applications (Smith 1981).

*Water contamination* as well as solvent cross-contamination can lead to acid formation. In addition, water contamination increases diffusion of solvents increasing evaporative loss. To avoid water contamination, the water separator should be cleaned and checked frequently for proper drainage. Next, the temperature of the water exiting the condenser coils should be maintained at 90 to 100°F. Finally, parts should be checked to see that they do not enter the degreaser while wet. This may call for using oil-based abrasives and cutting oils in production steps prior to cleaning.

*Sludge* that collects in the bottom of the tank should always be removed promptly. Contaminants such as paint absorb solvent, dissolve into solution, and reduce cleaning efficiency. Zinc and aluminum fines, which are particularly reactive in chlorinated solvents, can lead to acid formation, if allowed to collect. Organic soil contamination should not be allowed to exceed 10 percent for cold cleaning operations and 25 percent for vapor degreasers. When these levels are exceeded, acid formation can occur.

*Using appropriate makeup solutions for the solvent bath.* As solvents are used, their ability to neutralize acid lessens. Often, when an acid acceptance test indicates that a solvent is close to going acid, fresh solvent is added to

boost the level of stabilizers in the tank. This, however, is a poor practice, since the level of stabilizers in the tank can never be made equal to the level of stabilizers in fresh solvent. The proper technique is to analyze the solvent and add specific components rather than fresh solvent. Usually, the expense of analysis will be offset by the savings in solvent for tanks of 500 gallons or more (Durney 1984). This method should also be useful for facilities that recycle their solvent, since distillation removes most stabilizers from the solvent.

**Solvent standardization.** For facilities using a large number of cold cleaning tanks, standardizing the solvent used would help by increasing the potential for recycling and minimizing the chances of cross-contamination from other solvents. Standardizing in this context implies using a minimum number (preferably one) of types of solvents in all operations in the plant.

**Consolidating operations.** Once solvent standardization has been implemented, the next step is to consider consolidating cold cleaning operations into a centralized vapor degreasing operation. While cold cleaning solvents must usually be discarded when the level of contamination exceeds 10 percent, vapor degreasers can operate up to a level of 25 to 30 percent contamination. In addition, vapor degreasers provide much better cleaning, and the parts leave the unit dry.

Other waste reduction techniques based on better operating practices include locating cold cleaning tanks away from heat sources, controlling the amount of heat supplied to vapor degreasers, avoiding spraying parts above the vapor zone or cooling jacket, and avoiding solvent vapor drag-out.

Solvent vapor drag-out from a tank occurs when a workpiece is inserted or withdrawn from the tank too quickly. The speed of withdrawal of the work should not exceed 11 feet per minute. In addition, the geometry of the workpiece can affect drag-out. If the space between the wall of the tank and the workpiece is too narrow, then a piston effect will force solvent vapor out of the tank. As a general measure, the cross-sectional area of the work load should not exceed 50 percent of the tank's open area.

### **Aqueous Cleaners**

Aqueous cleaners include, as mentioned above, alkaline and acid cleaning solutions. Alkaline cleaners are employed to remove organic contaminants from metal surfaces and can replace solvent cleaners in many applications. Acid cleaners are used to remove oxidation, scale, and rust from metal surfaces. Aqueous cleaners are most commonly applied in heated soak tanks, often with spray units installed if alkaline solutions are being employed. Source reduction methods for reducing aqueous cleaning wastes include:

**Frequent removal of sludge.** Separator units designed to remove sludge and particulate matter continuously from alkaline or acid baths can reduce waste stream volumes and save on disposal costs. One typical unit for alkaline baths consisting of a pump, hydrocyclone and sludge retention tank has reduced replacement chemical costs in a steel cabinet manufacturing shop by 20 percent, and the time interval between dumping and total cleanout of the system has been lengthened from four to thirteen weeks (Report to Congress 1986).

**Use of dry cleaning and stripping methods.** Cleaning and stripping of parts can often be accomplished by employing sand or bead blasting techniques. In one decorative plating shop, hazardous sludge production was reduced 75 percent by replacing alkaline stripping of old paint and plating layers with sand blasting. The dry wastes produced were minimal, and were much less expensive to dispose of than the sludge (Jacobs 1986).

### **Abrasives**

Abrasive powders are usually mixed with an oil-based or water-based binder and are then applied to a polishing or buffing wheel. Waste from this operation consists of worn out cloth wheels saturated with abrasive, metal particles, binder, and various oxides. Wastes from vibratory or mass finishing operations consist of abrasive, metal particles, water, and oxides dispersed in a slurry. Alkaline or acid cleaners are sometimes added to the slurry so that additional cleaning action is provided. Usually slurries are discarded when the abrasive has undergone a given amount of attrition or breakdown. The following source reduction methods are applicable for abrasive cleaners:

**Use of greaseless or water-based binders for polishing or buffing.** When oil-based binders are used, the frictional heat generated during buffing can cause the binders to burn. This in turn leads to the need for additional workpiece cleaning such as alkaline soaking. When properly used, greaseless compounds leave the buffing wheel clean and dry (Durney 1984). Also, greaseless compositions adhere well to the surface of the wheel, extending wheel life.

**Use of liquid spray compositions.** Most abrasive compositions are formulated for use in bar form (the bar is held against the wheel to apply abrasive). With a liquid spray system, a spray gun applies the compound to the wheel automatically. Since the optimum quantity of compound can be maintained on the wheel more easily with a spray system, wheel wear due to compound deficiency and compound waste due to over-application are minimized. Also, since spray compounds are usually water-based, there should be no need for subsequent cleaning due to burned binder material deposits on the workpiece.

*Careful control of water level in mass finishing equipment.* If insufficient water is used in mass finishing operations, work items leaving the equipment will be dirty and the attrition rate of the abrasive and its replacement frequency will increase (Durney 1984). Water levels must thus be carefully metered in these operations.

*Synthetic abrasives.* Abrasive cleaning and deburring of workpieces is sometimes accomplished by putting both workpieces and abrasive grit into a tumbling barrel and rotating until the parts are finished. Beach sand and river rocks are often used as abrasives. These will grind down, however, into a large volume of fine silt mixed with metal fines that must be treated as a hazardous waste. This problem can be reduced by using aluminum oxide grit in place of beach sand, and ceramic abrasive deburring material in place of river rock.

#### *Rinsewater*

Water is used to remove or dilute cleaning solutions that are dragged out with cleaned parts. If these cleaning solutions are not removed, they can affect the quality of the work and contaminate subsequent cleaning and processing operations. Since rinsing is essentially a process of dilution, the general trend in the past was to use large volumes of water. Today, however, efficient rinsing is required to achieve the proper level of dragout dilution and also conserve water. By conserving water, capital and operating costs for waste treatment units are minimized. Source reduction methods for reducing cleaning solution drag-out and the amount of water required include:

- Proper design and operation of rack system
- Proper design and operation of barrel system
- Proper design and operation of rinse system
- Installation of spray rinses
- Installation of fog nozzles
- Chemical rinsing
- Deionized water use

#### *Proper Design and Operation of Rack System*

Through proper design and operation of a rack system, solution drag-out can be significantly reduced. Parts should be racked so that the surface is nearly vertical and the longest dimension is horizontal. Also, the lower edge should be tilted from the horizontal (this allows run-off to occur at a corner rather than the entire edge). Withdrawal from the cleaning solution should be made slowly and the part allowed to drain over the tank for a minute or two. Additional drainage time can be provided by installing sloped drain boards at the end of the tank.

For items with cup-shaped recesses, drainage can be a difficult problem. If the part cannot be positioned to allow for drainage, special measures must be taken. Some of these measures include drilling or repositioning drain holes in the part, tilting the rack as it is removed from the bath, and/or installing air jets to blow off cleaner solution from the part.

Rack maintenance is also important. If rack insulation is cracked, solution can be carried out in the gaps and fissures. In addition, exposure of the rack metal during electroplating operations can lead to contaminated bath solutions. Uninsulated racks used for cleaning should be stripped regularly since the rough surface will hold solution by capillary action.

#### *Proper Design and Operation of Barrel System*

While barrels are normally fully immersed during electroplating operations, maximum rinsing efficiency occurs when the barrel is only immersed partially. The proper depth and rate of rotation depends on many factors but normally occurs when the barrel is immersed to about 38 percent of its diameter. In most plants, rinse tanks for barrel operations are designed and operated the same way as electroplating baths (i.e., the barrel is fully immersed). After immersing the barrel, it is raised over the tank while rotating and is allowed to drain. At a minimum, two counterflow cold rinses and a final hot rinse should always be used.

#### *Proper Design and Operation of Rinse System*

Since the process of rinsing is one of dilution, good practice should assure that the rinse tank is well mixed at all times. Tanks can be mixed by agitating the water with oil-free air, introducing fresh water at the bottom of the tank, and by other mechanical means. The water in the tank should exhibit a rolling turbulence without undue splashing. For cleaners that are not very easy to rinse off, heated rinse tanks are often employed.

Once agitation and complete mixing in the tank have been assured, the next concern is the number of rinses. Pinkerton and Graham (1984) presented evidence that use of a second rinse can cut water requirements by over 90 percent. For facilities with limited floor space, single rinse tanks can often be converted to multiple rinses by welding one or more dams across the tank. Most modern facilities are designed with multiple rinse tanks after each cleaning operation.

If the spent rinsewater is used as makeup for evaporation from the process bath, hazardous chemicals are prevented from entering the waste streams, reducing the risk to the environment that they pose. If evaporation from the process bath is not great enough for the bath to accommodate

the quantity of spent rinsewater produced, an evaporator can be added to the process bath. Alternatively, some shops raise the temperatures of their process baths at night, adding the spent rinsewater as makeup the next morning.

*Installation of water sprays on rinse tanks.* For installations with single rinse tanks and limited space, rinsing efficiency can easily be increased by installing a spray system. By spraying work items with fresh water as they are raised above the rinse, the equivalent of an extra one-half counterflow bath is obtained. Sprays should be properly designed to provide uniform coverage on the part and not produce undue splashing. Spray rinsing is also beneficial on multitank counterflow systems where each spray unit is fed water from the succeeding rinse tank.

*Installation of fog nozzle on heated aqueous cleaner tanks.* A fog nozzle is a special high pressure water spray unit that produces a finely atomized mist of water or fog. Since the water is so finely dispersed, only a small amount of water is used compared to a normal spray unit. Therefore, fog nozzles can be used over heated cleaner tanks for rinsing work items without introducing a surplus of water. Two main benefits of using fog nozzles are that: 1) they help cool the part so that the cleaning solution has less chance of drying on the part; and 2) they reduce drag-out by diluting the solution retained on the part.

*Chemical rinsing.* In some facilities, rinse water from an alkaline cleaning operation is reused to rinse parts from an acid cleaning operation. The basic premise is to combine rinsing and waste treatment in one operation. While this procedure reduces the amount of waste rinse water generated and the degree of wastewater treatment required, the potential for contaminating the parts with metal hydroxide precipitates is increased. Therefore, this method should be limited to those parts not requiring rigorous cleaning.

*Use of deionized water for rinsing.* Use of regular tap water is a major source of impurities in any closed loop system. By employing deionized water, many rinses can be reclaimed using a simple evaporation system. In addition, use of deionized water can extend plating bath life by reducing impurity drag-in as well as the number of rejects produced. Many packaged systems commercially available can supply deionized water of adequate quality because most electroplaters do not require extremely high purity water.

### **Media Substitution**

*Replacement of solvents with less toxic solvents.* Since the choice of which cleaning medium to use is seldom clear cut, many opportunities exist for substituting one cleaning medium with another. Toxic solvents can often be replaced with safer alternatives. For instance, perchloroethylene

(PCE) and trichloroethylene (TCE) are currently being replaced by 1,1,1-trichloroethane in many applications. Benzene and other toxic aromatics are often replaced by aliphatic solvents such as Stoddard naphthas.

Other substitutes may include dibasic acid esters, terpenes, amines, or alcohols. Prerequisites include low flammability, low vapor pressure, low toxicity, high solvency and low cost.

Terpenes, essential oils isolated from plants through gentle heating or steam distillation, are especially promising as potential substitutes for many solvents as well as aqueous cleaners. Terpenes are less toxic and more biodegradable than most solvents. Limonene cleaners, commercially important terpenes made from oils of lemon or orange, are listed as GRAS (Generally Recognized As Safe) substances in the Code of Federal Regulation (Hayes 1987). Limonenes have tested favorably against solvents, solvent emulsions, and alkaline cleaners for removal of heavy greases, carbonized oils and oily deposits.

Reported disadvantages of terpenes include difficulty in separating oily wastes from them in order to recycle the cleaning solution. Ultrafiltration is being tested as one means to recover the cleaning solution. In addition, because of their low volatility, terpenes are not usable in vapor degreasing operations.

Surfactants added to terpenes forms emulsifiable cleaning compounds that are water rinseable. Products on the market include BIOACT (manufactured by Petrotem Inc.), a substitute for chlorinated solvents and chlorofluorocarbons (BIOACT's atmospheric ozone depletion factor is zero since it contains no chlorine or bromine) and Citrikleen, a limonene manufactured by Penetone (Tenafly, New Jersey) that can be sprayed, foamed or brushed on workpieces, or used in immersion baths.

*Replacement of solvents with aqueous cleaners.* There is currently a major effort to switch from cold tanks using non-halogenated solvents and vapor degreasers using halogenated solvents to cold tank alkaline and emulsion cleaners. This changeover is largely driven by regulatory pressure to reduce air emissions from degreasing operations.

Numerous examples exist of successful substitution of aqueous cleaners for solvents. In one case, an electronic manufacturing facility that originally cleaned printed circuit boards with solvents found that by switching from a solvent-based cleaning system to an aqueous-based system, the same operating conditions and workloads could be maintained. The aqueous-based system cleaned 6 times more effectively. This resulted in a lower product reject rate, and eliminated a hazardous waste (USEPA 1983a). The Torrington Company in Walhalla, S.C. also reduced

the hazard posed by its waste streams by replacing 1,1,1-TCA used to clean metal bearings with a considerably less expensive alkaline degreaser that employed a two-stage washer and hot air drier (Kohl, Moses and Triplett 1984).

Emulsion cleaners combine solvent cleaning with aqueous cleaning so that water-immiscible solvent is dispersed in the aqueous phase with the aid of emulsifiers, surfactants and coupling agents. The large surface area of the dispersed solvent phase can sometimes attain results achievable with pure solvent. Solvent vapor pressure and evaporation losses are suppressed in emulsion cleaners. Disadvantages include residual oil film on the part (which necessitates an additional cleaning step in applications where a high degree of cleanliness is required), relatively low saturation capacity, and difficulties in recycling by separation of oil and reconstituting the cleaner.

*Replacement of solvents with mechanical and thermal alternatives.* Solvents are often used to dry parts following a water rinse operation. As an alternative, air blast systems utilizing a high velocity air jet can blow water droplets and other contaminants from glass, metal, or wood parts. Dry stripping and cleaning using a plastic or sand blast media to clean and strip parts can reduce disposal costs and water usage and has been shown to significantly reduce labor costs. The blasting media can also be recycled. Hill Air Force Base in Ogden, Utah, has successfully employed plastic beads propelled by high pressure air jets to remove paint from aircraft exteriors. Besides eliminating generation of hazardous waste, the use of bead blasting improved personnel working conditions, was easier to perform than solvent paint stripping, cost less and used less raw material. Other abrasive blasting materials, such as sand and CO<sub>2</sub> pellets, are also used for paint stripping.

*Replacement of aqueous cleaners and strippers with abrasive media.* Use of abrasives can eliminate the need for aqueous cleaners in some situations. In one example, a manufacturer that cleaned nickel and titanium wire in an alkaline chemical bath installed a mechanical abrasive system. In another situation, a decorative electroplating shop reduced its hazardous sludge buildup 75 percent by using sandblasting rather than alkaline strippers to remove paint and old plating from workpieces about to be replated.

## RECYCLING METHODOLOGIES

### Solvents

In vapor degreasing, cold solvent cleaning and aqueous cleaning, the soil removed accumulates in the equipment. Eventually the solvent becomes too contaminated for further use and must be reclaimed or disposed of via incineration.

To simplify waste solvent handling and to make recycling feasible, the following procedures should be

followed:

- Keep solvents segregated. In the recycling process, it is much easier to separate a solvent from its impurities than to separate two solvents. Specific recommendations are to always segregate:
  - chlorinated from nonchlorinated solvent wastes;
  - aliphatic from aromatic solvent wastes;
  - Freon from methylene chloride; and
  - water waste from flammables.
- Keep waste solvents as free from water solids and garbage as possible. Label the container clearly, keep the container closed and, if possible, sheltered from rain. Drums should be covered to prevent contamination with water. Solids concentration should be kept at a minimum to allow for efficient solvent reclamation.
- Keep a chemical identification label on each waste container. Record the exact composition and method by which the solvent waste was generated.

EPA estimates that up to 50 percent of all solvent wastes are currently being segregated and managed for energy recovery, reclamation or recycling.

Solvent can be recycled on-site, or transported to off-site, commercial recycling facilities. On-site recycling of solvent is recommended to reduce transportation liabilities and is found to be economical when at least 8 gallons of solvent waste is generated per day (Schwartz 1986). Where recycling of solvent waste is viable, the choice between on-site versus off-site recycling must be made. Major factors that may influence a decision are shown in Table 5.

### On-site Solvent Recycling

Some of the most commonly used on-site recycling techniques are:

*Gravity separation.* Simple settling of solids and water is often sufficient for reuse of solvent. For example, paint thinners may be reused many times if solids are allowed to settle.

*Filtration.* Filters can be used to remove solids from many solvents thus extending solvent life. To minimize waste, reusable filters (e.g. metal mesh or filter bags) as opposed to disposable cartridges should be used when possible.

**Table 5. Evaluation of On-Site Recycling**

**Advantages**

- less waste leaving the facility;
- owner control of reclaimed solvent's purity;
- reduced reporting (manifesting); and
- reduction in reporting (manifesting); and
- lower liability
- possible lower unit cost of reclaimed solvent.

**Disadvantages**

- capital outlay for recycling equipment;
- liabilities for worker health, fires, explosions, leaks, spills, and other risks as a result of proper equipment operation;
- possible need for operator training; and
- additional operating costs.

**Reported Difficulties**

- loss of solvent during distillation process;
- low solvent recovery efficiency;
- installation problems; and
- maintenance problems.

**Batch distillation.** A batch still vaporizes the used solvent and condenses the pure vapors in a separate vessel. Solids or high boiling residues (>400°F) remain in the still as residue. Solvent stills range in size from 5 gallon to 500 gallon capacity.

For recycling a waste solvent from a vapor degreaser, the degreaser can be used as a batch still. This is often done by employing proper boil-down procedures. Detailed discussion of these procedures is available from major solvent suppliers.

In many applications, it is necessary to keep the water content of the recovered solvent to less than 100 ppm. This can often be accomplished by distilling off the solvent-water azeotrope, decanting water, and then drying the remaining solvent with a molecular sieve, ion exchange, or other desiccant. The water removed in this operation must then be either treated or drummed for disposal.

**Fractional distillation.** Fractional distillation is carried out in a refluxed column equipped with either trays or packing. Heat is supplied by a reboiler located at the bottom of the column while heat is removed at the top of the column by a condenser. Fractional distillation allows for separation of multicomponent mixtures or mixtures of solvents and contaminants with very similar boiling points.

**Fuel use.** Boilers can be adapted to burn waste solvent for the recovery of heating value. Generally, boiler fuels require a minimum flash point of 135°F. Thus only high flash point solvents (140°F minimum) are suitable. Federal regulations pertaining to the use of solvent as fuel may be found in the Code of Federal Regulations (CFR) 40, section 266.

## Off-Site Solvent Recycling

If recycling of waste solvent on site is impractical, several off-site recycling schemes are available. All of the items listed in Table 5 should be investigated before deciding on an off-site recycling scheme.

Some viable off-site recycling arrangements include the following:

**Toll recyclers** offer services to generators by supplying solvent wash equipment, solvent and waste recycling services. The solvent wash equipment is maintained by these companies and the solvent is replaced periodically. The used solvent is recycled at an off-site facility. Costs for these services range from 50-90 percent of new solvent cost.

Safety Kleen Inc. (headquartered in Illinois) provides a batch-tolling service for degreasing solvents, and leases the process equipment and solvents as one system. Safety

Kleen's mobile units provide fully-contained degreasing systems to automobile repair shops. Safety Kleen periodically replaces the spent solvent with fresh solvent. The spent solvent is then recycled at a central facility. This arrangement is popular with small quantity generators. Another advantage of the toll system is that each generator's solvents can be recycled separately. This separation reduces the chances of the recycled solvent being contaminated with substances foreign to the processes of the generator.

**Cement kilns** are successfully being used to recover the heating value and chlorine content of organic wastes that contain halogenated solvents (up to 4 percent chlorine by weight). If more chlorine is present, then fuel blending is employed.

**Waste exchanges** are not as much a technology as an information service. The principle behind a waste exchange is in matching a generator of waste with a facility that can use the waste as raw material. Wastes currently recycled through waste exchange include acids, alkalis, other inorganic chemicals organics and solvents, and metals and metal sludges. Of these wastes, solvents and metal wastes are most frequently listed by waste exchanges because of their high recovery value.

## Aqueous Cleaner Recycling

**Oil separation.** Aqueous cleaners contaminated with oily wastes can be recycled using oil separation techniques. Oil separators are designed for gravity separation of free floating oils, as well as some settleable solids, from water.

**Pickling bath recycling.** Pickling bath acids become increasingly diluted over time by the formation of ferrous salts. Closed-loop recycling is necessary when the acids become ineffective. Recycling of sulfuric acid baths involves crystallizing the ferrous salts into ferrous sulphate hydrates. The crystals are drained, washed and partially dried, and can be sold as a chemical product used in manufacturing inks, dyes, pigments and fertilizers, and as a flocculating agent in waste treatment plants. Recovered acid can be reused in the pickling tanks after fresh concentrated acid is added to bring it up to the desired strength (Krofchak and Stone 1975). Hydrochloric acid pickle liquors can be completely recycled, without generating any solid, liquid or gaseous waste streams. Unlike other mineral acids, hydrochloric acid can be removed from spent pickle liquors through vaporization, without decomposition into other compounds.

## Surface Treatment And Plating Wastes SOURCE REDUCTION METHODOLOGIES

### Process Solutions

Process solutions for surface treating and plating



contain high concentrations of heavy metals, cyanides, and other toxic constituents. Process baths are not discarded frequently, but rather are used for long periods of time. (The chemicals they contain, however, are lost, sometimes at high rates, through drag-out on workpieces, spills and leaks). Nevertheless, the baths do require periodic replacement due to impurity build-up or the loss of solution constituents by drag-out. A contaminated or exhausted plating solution is highly concentrated with toxic compounds and requires extensive treatment. The source control methods available for reduction of spent plating and other process waste include increasing solution life and material substitution.

*Increasing solution life.* The lifetime of a plating solution is limited by the accumulation of impurities and/or by depletion of constituents due to drag-out. The impurities come from five sources: racks, anodes, drag-in, water make-up, and air. Corrosion and salt buildup deposits on the rack elements will contaminate plating solutions upon dipping and falling into the solution. Proper design and maintenance (mainly cleaning) will minimize this form of contamination.

The use of purer metal for anodes also extends the plating solution life, because during plating, metal from the anode is dissolved in the plating solution, and impurities contained in the original anode matrix can eventually accumulate to prohibitive levels.

Efficient rinsing of the workpiece between different plating baths reduces the carryover of plating solution into the next bath. Using demineralized or distilled water as makeup to compensate for evaporation is preferred over tapwater, since tapwater may have a high mineral or solids content, which can lead to impurity buildup. Another method that has been successfully used to increase the longevity of plating solutions is periodic filtering to keep levels of impurities low. In many shops, continuous or daily circulation of plating baths through carbon or small-hole (typically 10 micron) filters have dramatically lengthened bath life by reducing sludge buildup, which eventually would impair plating quality (Normandy 1988; Foss 1988).

*Material substitution.* Cyanide plating solutions can be replaced with less toxic cyanide-free solutions. Cyanide-zinc solutions, for instance, can be replaced with non-cyanide, non-chelated alkaline zinc solutions eliminating the problem of handling cyanide-containing wastes. Replacing cyanide solutions with non-cyanide solutions, however, often requires upgrading of the degreasing/cleaning techniques used, because the non-cyanide replacements may require a much more thoroughly cleaned surface to ensure high quality plating. The primary barrier to non-cyanide bath use is that military contracts often

specify the use of cyanide solutions, thereby preventing electroplaters from using non-cyanide replacements.

Replacement of cadmium-based plating solutions is feasible in many applications. Cadmium is used in a wide variety of products for its excellent protective properties. Cadmium-plated products are highly resistant to corrosion in land and marine environments. For this reason, the U.S. military specifies cadmium plating for a large variety of naval and aerospace equipment. It is possible in some instances however to replace cadmium plating with other materials such as zinc, titanium dioxide (using vapor deposition), aluminum (using ion vapor deposition or ivodizing), and aluminum using spray-and-bake application. None of these coatings have exactly the same properties as cadmium, but nonetheless may prove to be satisfactory substitutes. Aluminum ion vapor deposition is a very attractive process, but is considerably more expensive than electroplating. Excellent adhesion and corrosion resistance and little or no hydrogen embrittlement is exhibited by both spray-and-bake aluminum coats and the Ivodized coat.

Replacement of hexavalent chromium with trivalent chromium offers important environmental advantages. Trivalent chromium is considerably less toxic than hexavalent. Trivalent systems use far lower concentrations of chromium metal and also produce few toxic air emissions, while hexavalent systems involve a reaction that produces hydrogen bubbles which entrain chromium compounds and carry them out of the baths. Trivalent chromium is readily precipitated from wastewater, while hexavalent chromium solutions must go through an additional step in a treatment system in which the chromium is reduced to its trivalent form before precipitation. It has been shown that trivalent chromium systems can successfully replace hexavalent ones for decorative chrome applications. Trivalent chromium systems are not suitable for hard chrome applications.

Because there can be a substantial amount of highly toxic waste generated during a chromium plating operation, the elimination of any unnecessary use of chromium would be beneficial from the environmental standpoint. For example, some automobile bumpers are currently being painted rather than plated during finishing operations.

*Process substitution.* Certain processes can offer an alternative to electro- and electroless plating. Hot dipping of tin and other metals, for instance, in which the workpiece is immersed in a molten metal bath, could provide a way of reducing toxic effluent levels. A disadvantage of hot dipping is that it is energy intensive, for the metal in the bath must be maintained in a molten state.

*Chemical coatings.* Chemical vapor deposition (CVD) is the gas-phase analog of electroless plating (Kirk-Othmer

1981), in that it is catalytic and involves a chemical reduction of a species to a metallic material which forms the coating. CVD coatings are extremely pure, and thus suitable for many electronic applications. The reactions require temperatures up to 1500°C, although work is in progress to design low temperature processes that can be used on workpieces unable to withstand high temperature.

In vacuum coatings, the metal coating is vaporized in a vacuum which is low enough to ensure that most of the evaporated atoms migrate to the workpiece with few collisions with background gas molecules. The atoms impinging on the workpiece condense to a solid phase. Thermal sources used to vaporize the coating include resistance heating, induction heating, electron-beam heating, and laser irradiation.

*Mechanical cladding and coating.* Metals can be bonded to the workpiece using mechanical techniques in which the coating material is forced under high pressure into contact with the workpiece. The pressure at the interface between the two metals must be high enough to disrupt and disperse boundary oxide films and initiate thermal interdiffusion and mechanical attachment. Roll bonding is a type of cladding in which one strip of metal is pressed onto another with the aid of bonding rollers. Metal claddings can also be melted into place using welding or casting techniques. Cladding generally produces thick coatings compared to other methods.

Metal powder can also be coated on to the workpiece. The 3M Company has developed a cold welding technique in which the workpiece, the metal powder, water, glass shot and additives are tumbled together in a barrel. Coatings are limited to ductile metals such as Cd, An, Sn, Pb, In, Ag, Cu, brass, and tin/lead solder; the method is generally suitable only for small parts, and it doesn't produce a fine surfaced, cosmetic coating. Costs are comparable to those for electroplating with afterbake (Kirk-Othmer 1981).

#### *Waste Rinsewater*

Waste rinsewaters account for the largest fraction of waste volume produced in surface treatment and plating processes. Any method of reducing the amount of rinsewater used will significantly reduce the total waste volume from a process. Large amounts of rinsewater are used to rinse off drag-out on a metal surface after the metal is removed from a plating or cleaning bath. Rinse waters usually contain dilute solutions of bath salts, such as cyanides and heavy metals. There are several methods available to reduce the amount and/or toxicity of waste rinsewater produced. The methods can be grouped into two techniques: drag-out minimization and rinsewater minimization. Drag-out minimization results in a decrease of the heavy metal

content of the rinsewater and of the ultimate waste (treatment sludge). Decreasing rinsewater consumption without reduction in drag-out may thus result in a smaller, but more toxic, volume of treatment sludge.

*Drag-out minimization.* By minimizing the amount of drag-out carried from a plating or cleaning bath to a rinsing bath, a smaller amount of water is needed to rinse off the workpiece. Also, less of the plating solution constituents leave the process, which ultimately produces savings in raw materials and treatment/disposal costs.

It must be stressed that drag-out minimization is not effective unless accompanied by a means of purging the bath of impurities that build up and that otherwise have no outlet. Impurities such as dirt, grease, and carryover from previous process baths that were purged from the plating bath by being dragged out on workpieces now must be removed by means such as periodic or continuous filtration, which is discussed earlier in this section. Otherwise, sludge will build up, plating quality will be impaired, and the bath will have to be disposed of sooner, raising the environment of risk and defeating the purpose of reducing the drag-out.

The amount of drag-out from a bath depends on the following factors:

- *Speed of workpiece withdrawal and drainage time.* The rate at which the workpiece is withdrawn, the time allowed for drainage over the mother tank, as well as the orientation with which the work is withdrawn from the bath, affect the amount of drag-out produced.
- *Surface tension of the plating solution.* A plating solution with a high surface tension tends to be retained in the crevices and surface imperfections of the workpiece when it is removed from the plating bath, thus increasing drag out.
- *Viscosity of the plating solution.* Highly viscous solutions result in larger amounts of drag-out.
- *Physical shape and surface area of the workpiece.* The shape of the workpiece affects the amount of plating solution that gets dragged out of the bath. With all other parameters remaining the same, a larger workpiece surface area results in more drag-out. It is noted that barrel plating operations produce more drag-out than rack plating.

Drag-out minimization techniques typically include:

*Reducing the speed of withdrawal of workpiece from*

*solution and allowing ample drainage time.* The faster the workpiece is removed from the bath, the higher the drag-out will be. The workpiece should be removed as slowly and as smoothly as possible. Ample time should be allowed for draining the solution back to the tank, especially for higher viscosity solutions. Usually, 30 seconds allows most of the drag-out to drain back to the tank. However, in applications where quick drying is a problem, or where production schedules do not allow a long drainage time, a 10 second draining still permits good drag-out recovery.

*Lowering the concentration of plating bath constituents.* A decrease in the concentration of metal salts and other components of the plating solution directly reduced the amount of hazardous substances dragged out of the bath. It also leads to lower solution viscosity, which results in less drag-out volume. Many concentration reductions have been successfully implemented. Notably, it has been found that acceptable chromium plate can be obtained from baths containing only 25-50 g/l  $\text{CrO}_3$ , compared to traditional concentrations of 250 g/l  $\text{CrO}_3$  (Report to Congress 1986).

*Use of surfactants.* Wetting agents have been used to lower the surface tension of plating solutions and reduce drag-out. A solution with a high surface tension is retained in the crevices and surface imperfections of the workpiece upon removal from the plating bath. Only nonionic wetting agents, which will not be degraded by electrolysis in the plating bath, should be employed. The use of surfactants is sometimes limited due to their adverse effect on the quality of the plate produced.

*Increasing plating solution temperature.* The increased temperature lowers both the viscosity and the surface tension of the solution, thus reducing drag-out. The resulting higher evaporation rate may also inhibit the carbon dioxide absorption rate, slowing down carbonate formation in cyanide solutions. Unfortunately, this benefit may be lost due to the formation of carbonate by the breakdown of cyanide at elevated temperatures. Additional disadvantages of this option include higher energy costs, higher chance for contamination due to increased make-up requirement, and increased need for air pollution control due to the higher evaporation rate.

*Proper positioning of the workpiece on the plating rack.* When a workpiece is lifted out of a plating solution on a rack, some of the excess solution on its surface (drag-out) will drop back into the bath. Proper positioning of the workpiece on a rack facilitates drainage of the drag-out back into the bath. The position of any object which will minimize the carry-over of drag-out is best determined experimentally, although the following guidelines were found to be effective (Durney 1984):

- Orient the surface as close to vertical as possible.
- Rack with the longer dimension of the workpiece horizontal.
- Rack with the lower edge tilted slightly from the horizontal so that the runoff is from a corner rather than an entire edge.

*Improved drag-out recovery.* A drain board positioned between a plating bath and rinse bath can capture the solution dripping from a workpiece and route it back to the plating bath. The drain board can be made of either plastic or metal. For acidic solutions, drain boards can be made of vinyl chloride, polypropylene, polyethylene, or Teflon-lined steel. Another option is to incorporate a drip tank between the plating bath and the rinsing bath. The drip tank is an empty tank for collecting the dripping solution, which can be returned to the plating bath.

A third alternative is the use of a still rinse tank with contents periodically transferred back into the plating. Installing a still (or dead) rinsing tank immediately after a plating bath allows for metal recovery and lowered rinsewater requirements. In such a system, the workpiece is immersed in the still rinse tank following the plating operation. Since the still rinse has no inflow or outflow of water, the concentrations of the plating bath constituents build up in it. When the concentrations become sufficiently high, the contents of the still bath is not discarded but is used to replenish the plating bath.

Rinsewater can also be reduced through system redesign. The aim of rinsewater minimization is to use the smallest volume of water necessary to adequately clean the workpieces. While reducing rinsewater requirements does not directly reduce the quantity of hazardous materials in the plating line effluent, it does reduce the load on the treatment plant (which can result in more hazardous substance removal or neutralization from the waste stream) as well as saving money through reduced water requirements. Several system design methods exist for lowering rinsewater requirements, including:

*Rinse tank design.* The most important factor in the design of rinse tanks is ensuring complete mixing of rinsewater, thus eliminating short circuiting of feed water and utilizing the entire tank volume (Pollution Prevention Tips. 1985 (a)). In a rinse tank in which the water distribution line is located on the bottom at the far end of the tank from where the work is introduced, incoming water creates a rolling action that mixes the tank contents, and helps to scour workpieces clean. A flow control valve can also be installed in the distribution line to restrict freshwater feed to an optimum level. A conductivity control system can be used as an alternative to a flow

control valve, which measures the level of dissolved solids in the rinse tank, and opens the freshwater feed valve at a predetermined maximum solids level. Air agitation removes plating solution clinging to the workpiece surface, and also mixes the tank contents. Installing the air distribution line diagonally across the bottom of the tank helps even distribution of the air.

**Multiple rinsing tanks.** The use of multiple rinsing tanks is one of the most common rinsewater reduction techniques, and can dramatically reduce rinsewater requirements. In a typical counterflow three-tank rinsing system, the workpiece initially enters the first rinse tank, which has the most contaminated rinsewater. It is then moved to the second tank, and then to the last, where it contacts fresh rinsewater. Fresh rinsewater enters only the last (third) rinsing tank. The water from the third tank flows into the second tank and then into the first tank, from which it can be routed either into the plating tank as a make-up, or to the treatment system.

It is preferable to route the rinse system effluent back into the plating bath, in order to prevent release of the chemicals they contain to the environment. One chrome plater (Foss 1988) whose shop was examined for this study accomplished this by lowering the flow through his counterflow system to 0.5 gal/min or less, and installing an evaporator on the plating tank capable of vaporizing up to 350 gal/day.

A second wastewater reduction method with a high implementation potential is the reuse of rinsewater. Electroplating operations use rinsewater at several stages in the process, and it is often possible to use the same stream at more than one stage. The main problem with this technique is that the quality of the product must be monitored carefully. A rinse stream can be used a second time only if the contaminants from the first rinse do not interfere with the quality of the second rinse.

**Reactive Rinsing.** This technique takes advantage of the chemical makeup of the rinsewater to not only reduce water usage, but to increase rinsing efficiency as well (Pollution Prevention Tips 1985 (c)). For example, a typical nickel plating line might consist of the following sequential processes:

- Alkaline Cleaning
- Rinse
- Acid dip
- Rinse
- Nickel Plating
- Rinse

Water from the nickel rinse tank can be fed back into the acid dip rinse tank allowing nickel plating solution dragged out of the process bath to be dragged back into it. This will not harm the rinse, and will allow the water feed to the acid rinse tanks to be turned off. Thus, both water and process chemicals are conserved, and the quantity of toxic process chemicals in the effluent is reduced.

The acid rinse can be further recycled to the alkaline cleaner rinse tank. This conserves water by allowing the fresh water feed to the alkaline rinse to be turned off, and also improves rinsing efficiency by helping to neutralize the dragged in alkaline solution. This will prolong the life of the acid bath because the rinsewater dragged into it will already be partially neutralized. Thus the acid bath will not have to be dumped as often.

Remember that whenever an open-loop system process line is replaced by or modified into a closed-loop arrangement, attention must be given to periodically purging the impurities that will build up.

**Fog nozzles and sprays.** Spraying water directly onto a workpiece can rinse contaminants from it using considerably less water than immersing the part in a bath. A major limitation of spraying is that it is not effective on many oddly-shaped objects, since the spray cannot make direct contact with the entire surface of the object. But for simple workpieces such as sheets, it is highly effective. A variation on the spray nozzle is the fog nozzle. A fog nozzle uses water and air pressure to produce a fine mist. Less water is used than with a conventional spray nozzle.

**Automatic flow controls.** The lowest possible rinsewater flow rate which can efficiently rinse a workpiece can be determined for all systems. This flow then can be

automatically controlled to avoid variations associated with water line pressure changes and manual control by operators.

*Rinse bath agitation.* Agitating a rinsing bath mechanically or with air increases the rinsing efficiency and cuts down on water demand.

#### **Treatment Wastes**

Toxic metal sludges result from conventional treatment processes used to remove metals from aqueous wastes. Metals are usually precipitated as hydroxides or carbonates, resulting in sludges which require further treatment and disposal. Lime is commonly used as the precipitating agent. The volume and toxicity of the sludge produced can be lowered by reducing the metal content in the plating and rinse waters, or by using different precipitating agents. Methods available to accomplish this include:

*Use of different precipitating agents and other treatment chemicals.* Normally, hexavalent chromium in waste rinsewater or plating solutions is treated by being reduced to trivalent chromium with a reducing agent, followed by precipitation with lime. Sodium hydroxide has been examined as a substitute for lime (Report to Congress 1986). Sodium hydroxide precipitation agents produced 12 percent less dry solids than lime precipitation.

Chemical treatment to destroy cyanides and remove metal contaminants is the most common type of wastewater treatment for plating and surface treating lines. Treatment processes create hazardous waste sludges. The sludge volume generated is present in part on proper selection of treatment chemicals. Caustic soda used as a neutralizer and precipitation agent, for instance, can in some situations generate up to 90 percent less sludge than using lime. Polyelectrolyte conditioners employed as flocculating agents to improve floc formation do not contribute to sludge formation as do alum (a common coagulant) and ferric chloride, a flocculant (PRC 1988).

*Use of trivalent chromium instead of hexavalent chromium for plating.* One operation reported a 70 percent reduction in sludge production when trivalent chromium was used for plating instead of hexavalent chromium, because it avoided the necessity of precipitating gypsum associated with excess sulfate ions introduced during the reduction step. (Report to Congress 1986).

*Waste segregation.* Segregating wastes and treating them separately can also reduce sludge volumes generated. Ferric sulfide, for instance, is useful for breaking down metal complexes in waste streams containing chelating agents. But the iron in ferric sulfide precipitates out and leads to considerable sludge generation. Ferric sulfide use can be minimized if chelating agent waste streams are kept

separate from others. Batch treating spent process baths rather than adding them to the wastewater treatment stream can also reduce waste generation. The spent baths can be analyzed for contaminant levels, and just the necessary amount of chemicals added to treat it. (PRC 1988)

By isolating cyanide-containing waste streams from waste streams containing iron or complexing agents, the formation of cyanide complexes is avoided, and treatment made much easier (Dowd 1985). Segregation of wastewater streams containing different metals also allows for metals recovery or reuse. For example, by treating nickel-plating wastewater separately from other waste streams, a nickel hydroxide sludge is produced which can be reused to produce fresh nickel plating solutions. Scrubber waste from chromium plating baths, if segregated, has been used as makeup for the bath, resulting in less discarded waste and increasing the longevity of the plating solution.

*More efficient sludge dewatering.* The volume of sludge produced can be greatly reduced through the use of new dewatering technologies which remove a greater percentage of water than traditional dewatering techniques (Report to Congress 1986). These involve efficient filter presses and thermal and air-drying techniques that can reduce the sludge to a nearly-dry cake.

#### **Source Reduction for Other Types of Metal Surface Treatment**

*Case hardening.* Case hardening processes involving diffusion of carbon or nitrogen into the workpiece requires source materials from which these elements can be generated. After the case hardening is completed, these source materials frequently become hazardous wastes. Source reduction for case hardening operations frequently involves choosing cleaner processes. For instance, pack carburizing uses solid pack materials such as coke or charcoal as a source of carbon. Spent packing must be disposed of as hazardous waste. This waste stream can be eliminated, however, if gas carburizing is employed. Gas carburizing burns natural gas in a sealed furnace as a source of carbon and produces no hazardous waste stream.

The salt baths in some nitriding and cyaniding processes also constitute hazardous wastes when spent. Nitriding and cyaniding baths for example, contain sodium and potassium cyanide and cyanate. Implementation of gas nitriding eliminates this waste stream. Gas nitriding employs ammonia gas to supply the nitrogen, and produces no hazardous waste stream.

Another possibility for source reduction in case hardening operations, especially in those involving ferrous metals, is to switch to applied energy hardening methods that generate a case through localized heating and

quenching, without use of chemicals. It is the existing carbon content of the metal that facilitates the hardness response when heated.

## RECYCLING METHODOLOGIES

Recycling and resource recovery include technologies that either directly use waste from one process as raw material for another process or recover valuable materials from a waste stream before the waste is disposed of. Some of the spent chemical process baths and much of the rinsewater can be reused for other plant processes. Also, process chemicals can be recovered from rinsewaters and sold or returned to the process baths. This section describes some of the recycling and resource recovery technologies available to the metal finishing industry.

### *Waste Material Reuse*

The more thoroughly a metal finisher understands the chemistry of their waste streams, the better able they are to assess their potential for reuse as raw materials, or in other applications. Successful recycling requires a change on the part of management and plant staff, to view their waste streams as resources, rather than as something to be thrown away.

After rinse solutions become too contaminated for their original purpose, they may be useful for other rinse processes. For example effluent from a rinse tank that follows an acid cleaning bath can sometimes be reused as influent water to a rinse tank following an alkaline cleaning bath. This technique must be used with caution, however, for it can lead to precipitation problems.

The drag-out film on the workpieces coming from the alkaline bath is alkaline. Recycled water from acid bath rinses has an acid pH, and thus tends to neutralize the drag-out film. This reduces its viscosity and accelerates the rinsing process (PRC 1988; USEPA 1982).

Other rinsewater reuse opportunities are also available. Acid cleaning rinsewater effluent can be used as rinsewater for workpieces that have gone through a mild acid etch process. Effluent from a critical or final rinse operation, which is usually less contaminated than other rinse waters, can be used as influent for rinse operations that do not require high rinse efficiencies. Another option is using the same rinse tank to rinse parts after both acidic and alkaline baths.

Spent process baths can also be reused for other purposes. A common example is to use spent acid or alkaline cleaners for pH adjustment during industrial waste treatment. Typically, these cleaners are dumped when contaminants exceed an acceptable level. However, these solutions remain acidic or alkaline enough to act as pH

adjusters. Alkaline cleaners, for instance, can be used in chrome reduction treatment. Since spent cleaners often contain high concentrations of metals, they should not be used for final pH adjustments, however.

### *Metal Recovery and Water Reuse*

In the past, metal recovery from metal finishing wastewater was not considered economical and was rarely done. Present effluent pretreatment standards, however, have dramatically increased the cost of treatment. Also, the cost of handling and disposing of spent process baths and sludges containing heavy metals has increased significantly because of the increased regulatory requirements placed on the handling and disposal of hazardous wastes. As a result, metal finishers may find it economical to recover metals and metal salts from spent process baths and rinsewater and to reuse rinsewater.

The waste reduction and economic savings actually achieved through metal recovery will depend on the individual metal finishing plant. Factors that will determine whether metal recovery is economically justifiable include the volume of waste that contains metals, the concentrations of those metals in the waste, and the potential to recirculate some of the metal salts. Many systems may not be economically feasible for small surface treatment and plating operations because the capital costs of installing the necessary equipment might outweigh the saving from recovering process chemicals.

Metal recovery can be achieved in two ways: (1) recovered metal salts can be recirculated back into process baths, or (2) recovered elemental metal can be sold to a metals reclaimer or reused in the plating process. Some of the technologies that are being successfully used to recover metals and metal salts include:

- Evaporation
- Reverse osmosis
- Ion exchange
- Electrolytic recovery
- Electrodialysis

While these treatment technologies are typically used to recovery chemicals from rinsewater effluent, they can also be employed for spent process baths. The wastewater that is produced after the metal recovery is often pure enough to be reused for rinsing.

Recovery systems can be used strictly for rinsewater recycling and not for chemical recovery. In that case, rinsewater waste streams need not be segregated since process chemicals are not being recovered. Rinsewater

effluent from a variety of plating or cleaning processes can be commingled and fed to a single, centralized recycling unit, such as ion exchange. The effluent can then be returned to the rinse systems and the residual disposed of.

Various methods for recovering process chemicals and rinsewater from rinsewater effluent are described below:

*Evaporation.* Evaporation has been successfully used to recover a variety of plating bath chemicals. Water is boiled off from rinsewater to reduce its volume sufficiently to allow the chemical concentrate to be returned to the process bath. The water vapor is condensed and can be reused in the rinse system. There are two basic evaporator designs that are typically used: atmospheric and vacuum evaporation (Metals Handbook 1987). Atmospheric evaporation principles are similar to those of a heated open tank, with the exception that the heated liquid is sprayed over plastic packing in order to increase its surface area and accelerate evaporation. Atmospheric evaporation works well for chrome plating lines because they can do double duty as plating bath fume scrubbers. Atmospheric evaporators have lower capital costs than vacuum evaporators, but suffer from the disadvantage that vaporized water is not recovered. When evaporation is performed under partial vacuum conditions, temperatures can be low enough to prevent degradation of plating additives. Because evaporation does not remove contaminants from the concentrate, it is necessary that the system have a method of controlling buildup of metallic and organic impurities. Additional recycling techniques such as ion exchange can be used for this purpose.

There are limitations to use of evaporation, one of the most serious being that it is a very energy intensive methodology and is generally only economically feasible when employed in conjunction with multistage counter-current rinse systems or other methods that reduce the quantity of rinsewater required.

A variation on standard evaporation technology that is much less energy intensive is the mechanical vapor recompression vaporization process. This uses the same evaporation separation principle, but an increased vacuum is employed so that water evaporates at temperatures of 50°F to 70°F.

*Reverse osmosis.* Reverse osmosis (RO) is a pressure-driven membrane separation process. The RO process uses a semipermeable membrane that permits the passage of purified water while not allowing dissolved salts to pass through. These salts can be recovered and returned to the process bath. The permeate rinsewater can then be returned to the rinse system for reuse. The most common application

of RO technologies in metal finishing operations is the recovery of drag-out from acid nickel process bath rinses. RO membranes are not suitable for solutions having high oxidation potential such as chromic acid. In addition, the membranes will not completely reject many nonionized organic compounds, and thus other methods such as activated carbon treatment must be used in conjunction with RO.

*Ion exchange.* Ion exchange (IE) can be used to recover drag-out from a dilute rinse solution. The chemical solution is passed through a series of resin beds that selectively remove cations and anions. As the rinsewater is passed through a bed containing the resin, the resin exchanges ions with the inorganic compounds in the rinsewater. The metals are then recovered from the resin by cleaning the resin with an acid and/or alkaline solution. The treated water is of high purity and can be returned to the rinse system for reuse. IE units can be used effectively on dilute waste streams and are less delicate than RO systems. A common use of ion exchange for process bath recovery is for the treatment of rinsewater from a chromic acid process bath.

IE equipment requires careful operating and maintenance practices. In addition, recovery of chemicals from the resin columns produces significant volumes of regenerant and wash solutions, which may add to the wastewater treatment load.

*Electrolytic recovery (Electrowinning).* Electrowinning is the recovery of the metallic content from solution using the electroplating process. It is employed to recover a variety of metals, including cadmium, tin, copper, solder alloy, silver and gold. In a typical electrowinning process, cathodes made of thin starter sheets of the metal being recovered, or stainless steel blanks from which the recovered metal can be stripped, are mounted in an open tank. As the current passes from the anode to the cathode, the metal deposits on the cathode. This type of system generates a solid metallic slab that can be reclaimed or used as an anode in an electroplating tank.

Several basic principles well known to the electroplating industry are employed in electrolytic recovery: expanded cathode surface area, close spacing between cathode and anode, and recirculation of the rinse solution. Electroplaters can design their own units by closely spacing parallel rows of anodes and cathodes in a plating tank and circulating rinse solutions through the tank. Air agitation is especially useful in most situations, increasing plating quality and current efficiency. Electrowinning can also be used on spent process baths prior to their treatment in the wastewater treatment system.

*Electrodialysis.* Electrodialysis employs selective



membranes and an electric potential as a driving force to separate positive from negative ions in the solution into two streams. To accomplish this, the rinse solution is passed through cation and anion-permeable membranes. Cation exchange membranes allow cations such as copper or nickel to pass, while anion exchange membranes pass anions such as sulfate, chloride or cyanide. The concentrated solutions can be recycled to the plating baths, while the ion-depleted water can be recycled through the rinse system. While electrowinning is most efficient for recovering metals from concentrated solutions such as spent plating baths, electrodialysis is very effective on dilute solutions like waste rinse waters.

## Paint Wastes

### SOURCE REDUCTION METHODOLOGIES

#### Empty Containers

Facilities that use small quantities of paint and a large variety of colors often purchase paint in small cans and containers (less than five gallons) for use in spray gun equipment. After emptying the can of paint into the spray gun's holding cup, a coating of paint remains inside the can. Since these cans are seldom cleaned, the entire can must be discarded as waste. Also included in this waste stream should be outdated or leftover paint removed from storage. Source reduction methods for this waste stream include:

*Waste segregation.* By preventing the contamination of non-hazardous materials such as trash with potentially hazardous materials such as solvent-based paint), the volume of hazardous waste will be reduced.

*Bulk purchasing.* Container waste is generated by the paint that remains inside a can after the can is emptied and by the paint that is placed in storage, not used, and becomes outdated. Facilities should strive to consolidate paint use so that the purchase of paint in bulk is practical. Since one large bulk container has much less surface area than an equivalent volume of small cans, the amount of wasted paint is much less. Large bulk containers can often be returned to the paint manufacturer for cleaning and reuse (while cleaning still generates some waste, the paint manufacturer is in a better position to handle it).

*Minimizing residuals.* When the purchase of paint in bulk containers is not practical, then paint should be purchased in the smallest amount required so as to minimize the amount of residual. Workers should not open a one gallon can of paint when only a quart or two are required. While the per unit cost of paint when purchased in various small quantity containers is greater than the cost of paint when purchased in larger quantities, the savings in reduced

paint wastage and disposal costs could still be substantial.

#### Paint Application Waste

The wastes generated during paint application are primarily due to: 1) paint overspray, and 2) the failure of all of the paint to reach the target. The following source reduction measures are noted:

*Use of paint application equipment with low overspray characteristics.* When comparing different types of paint application equipment, the transfer efficiency or degree of paint overspray produced can vary considerably. Brewer (1980) lists the following efficiency ranges for several different spray systems:

Spray Method	Efficiency
Conventional air-atomized	30-60%
Conventional pressure-atomized	65-70%
Electrostatic air-atomized	65-85%
Electrostatic centrifugally-atomized	85-95%

Other types of equipment that can yield even higher efficiency values are roller and flow coating machines (90 to 98 percent) and electrocoating systems (90 to 99 percent). Roller and flow coating machines, however, are limited in their applicability based on the shape of the parts. Electrocoating systems require a shift from solvent-based to waterbased paint.

#### Operator Training

Since many spray systems are manually operated, the equipment operator has a major impact on the amount of waste produced. When air pressures are set too high, the paint has a tendency to bounce off the surface and increase overspray. Another reported factor affecting overspray is the practice of arching the spray gun instead of keeping it perpendicular to the surface. When the gun is arched 45 degrees away from the surface at the end of each stroke, overspray can be great and an uneven coat of paint can result. Manual operations have been eliminated altogether in many facilities with the use of robots.

Preventive maintenance also plays a critical role in reducing the amount of overspray, stripping waste, and equipment cleaning waste produced. Whenever a bad finish is produced, the paint is normally stripped off and the entire paint application procedure is begun again. By maintaining all application equipment in good working order, the likelihood of producing a bad finish is lessened. Spray guns should be cleaned after use or whenever there will be an appreciable interval between use. For hand-held units, a solvent rinse with occasional blow-back (accomplished by covering the fluid tip and operating the trigger; this blows the paint back to its container) is



adequate. All moving parts should be lubricated frequently and properly adjusted. A spray gun should always be able to provide a smooth change from solid fan to round cone by adjustment of the controls.

Roller coating and flow coating machines must also be properly maintained if they are to produce good finishes. Rollers on roller coating machines should be cleaned regularly to remove dried paint and inspected for swelling of the material. If swelling is evident, the rollers should be replaced immediately. Curtain or flow coating machines have a curtain head that must be kept clear at all times. If this aperture becomes blocked, the curtain will break and give an uneven finish. To clean the machine, solvent should first be circulated through the machine. After this, the aperture should be fully opened and cleaned with a soft rag or brush. Metal instruments should never be used for cleaning the curtain head.

By fully inspecting parts before they are painted, the painting of potential rejects can be avoided. Whenever a part is painted and then rejected, additional stripping, cleaning, and painting wastes are generated. If potential rejects are discovered before painting, they can probably be corrected (cleaned if the problem is contamination) and then painted with very little increase in waste generation.

#### **Material Substitution**

Conventional solvent-based systems for paint application often pose potential health hazards, due to the emission of toxic solvents and the disposal of a large amount of waste paint sludge. To minimize the quantity and toxicity of waste paint requiring disposal, new coating types have been developed which eliminate the hazardous components of the paint and also allow for maximum reuse of paint overspray, thus increasing the efficiency of the paint application process. These alternatives include the use of water based, radiation-curable, or powder coating techniques.

**Water-based coatings.** Water-based coatings are paints containing a substantial amount of water (often as much as 80 percent) in place of the volatile solvent. The polymers used include alkyd, polyester, vinyl acetate, acrylic, and epoxies, and can be dissolved, dispersed or emulsified. These coatings are supplied as baking finishes, as well as air-drying formulations. One feature which makes water-based coatings attractive is that no major equipment changes are necessary to apply water-based coatings with solvent-based coating equipment. Another advantage lies in the ease of recovering paint overspray. Overspray from a water-based coating can be collected or captured with water in the spray booth. The solution can subsequently be concentrated and reused as paint again. In addition to

substantial reductions in environmental hazards due to significantly lower air emission levels and smaller amounts of waste paint sludge generated, water-based coatings can also provide energy savings by making possible the recirculation of the hot air used to cure the paint. Water-based coatings have increasingly been used by industry as an alternative to solvent-based systems. For example, Emerson Electric Company has reported the use of a water-based electrostatic paint system in place of a conventional organic solvent paint system (Huisingh et al. 1985), resulting in a number of favorable changes, including:

- Improved quality of application.
- Decrease of down time from 3% to 1%.
- Reduction in generation of aromatic waste solvent by 95%.
- Reduction of paint sludge by 97%.
- Increase in efficiency with up to 95% recovery and reuse of paint.

The new system also reduced hazardous waste disposal costs and decreased personnel and maintenance costs by 40%.

The appendices to this booklet contain a case study of another facility that had favorable results from switching to a water-based painting system.

**Radiation-curable coatings.** Another alternative to solvent-based coatings is radiation-curable coatings. These coatings do not contain or use organic solvents. Reactive monomers are applied as a liquid to a surface which is then exposed to high energy radiation such as UV or IR light. Radiation-curable coatings account for a substantial fraction of the curable coating market (Campbell and Glenn 1982). The advantages of using this coating technique include the reduction in waste from solvent loss and a decrease in energy and maintenance requirements.

**Powder coatings.** Powder coatings represent an attractive third alternative to solvent-based coatings. Use of powder coatings has been referred to as a "dry painting process". The process is simple in operation and can be done manually or by highly automated equipment. With manual systems, the powder is sprayed on the object and the overspray is readily retrieved and recycled, something that is very difficult to do with liquid paints. Overspray and other unused powder are returned to the feed hopper for reuse. This ability to recycle the coating material provides a very high efficiency-use ratio. In a well-designed spray system, the coating powder remains clean at all times and the potential for waste generation (contaminated powder) is nearly zero. Powder coatings can also be effectively

applied in a fluidized bed (Report to Congress 1986).

## RECYCLING

Paint application equipment - spray guns, hoses, as well as brushes and rollers - is often cleaned with solvents. Cleaning wastes can sometimes be recycled in ways such as (Lorton 1988):

- collecting and reusing the solvent-paint mixture

in the next compatible batch of paint as part of the formulation;

- distilling the mixture either on- or off-site, in order to reuse the solvent and possibly the paint as well;
- separating out the paint sludge through filtration, centrifugation, or decantation, and reusing the solvent, and
- collecting the cleaning wastes and reusing for cleaning - perhaps in another application - until the solvent is too contaminated for further use.

## SECTION 4

### GUIDELINES FOR USING THE WASTE MINIMIZATION ASSESSMENT WORKSHEETS

Waste minimization assessments were conducted at several fabricated metal facilities in Los Angeles area. The assessments were used to develop the waste minimization questionnaire and worksheets that are provided in the following section.

A comprehensive waste minimization assessment includes a planning and organizational step, an assessment step that includes gathering background data and information, a feasibility study on specific waste minimization options, and an implementation phase.

#### Conducting Your Own Assessment

The worksheets provided in this section are intended to assist facilities in systematically evaluating waste generating processes and in identifying waste minimization opportunities. These worksheets include only the assessment phase of the procedure described in the *Waste Minimization Opportunity Assessment Manual*. For a full description of waste minimization assessment procedures, refer to the EPA Manual.

Table 6 lists the worksheets that are provided in this section.

**Table 6. List of Waste Minimization Assessment Worksheets**

1. Plant Description
2. Process Identification
3. Waste Minimization Program Organization
4. Input Materials Summary
5. Material Storage and Dispensing Practices
6. Process Flow Diagram
7. Process Information
8. Documentation Available
9. Products Summary
10. Waste Stream Identification
11. Individual Waste Stream Generation and Characterization
12. Waste Stream Summary
13. Waste Minimization Options

Plant _____  Date _____	<b>Waste Minimization Assessment</b>  Proj. No. _____	Prepared By _____ Checked By _____ Sheet <u>1</u> of <u>1</u> Page ____ of ____
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**WORKSHEET**  
**1**

**PLANT DESCRIPTION**

**Firm:** \_\_\_\_\_

**Plant:** \_\_\_\_\_

**Department:** \_\_\_\_\_

**Area:** \_\_\_\_\_

**Street Address:** \_\_\_\_\_

**City:** \_\_\_\_\_

**State/ZIP Code:** \_\_\_\_\_

**Telephone:** (     ) \_\_\_\_\_

**Major Products:** \_\_\_\_\_

\_\_\_\_\_

**SIC Codes:** \_\_\_\_\_

**EPA Generator Numbers:** \_\_\_\_\_

**Major Unit or:** \_\_\_\_\_

**Product or:** \_\_\_\_\_

**Operations:** \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Plant/Equipment Age:** \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_



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WORKSHEET

**3**

**WASTE MINIMIZATION  
PROGRAM ORGANIZATION**

FUNCTION	NAME	LOCATION	TELEPHONE NO.
Program Manager			
Plant Program Coordinator			

**Organization Chart**  
(sketch)

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WORKSHEET

**4**

**INPUT MATERIALS SUMMARY**

Attribute	Description <sup>1</sup>		
	Stream No. _____	Stream No. _____	Stream No. _____
Material Name/ID			
Source/Supplier			
Hazardous Component			
Annual Consumption Rate			
Purchase Price, \$ per _____			
Overall Annual Cost			
Delivery Mode <sup>2</sup>			
Shipping Container Size & Type <sup>3</sup>			
Storage Mode <sup>4</sup>			
Transfer Mode <sup>5</sup>			
Empty Container Disposal/Management <sup>6</sup>			
Shelf Life			
Supplier Would			
- accept expired material (Y/N)			
- accept shipping containers (Y/N)			
- revise expiration date (Y/N)			
Acceptable Substitute(s), if any			
Alternate Supplier(s)			

- <sup>1</sup> stream numbers, if applicable, should correspond to those used on process flow diagrams.
- <sup>2</sup> e.g., pipeline, tank car, 100 bbl. tank truck, truck, etc.
- <sup>3</sup> e.g., 55 gal. drum, 100 lb. paper bag, tank, etc.
- <sup>4</sup> e.g., outdoor, warehouse, underground, aboveground, etc.
- <sup>5</sup> e.g., pump, forklift, pneumatic transport, conveyor, etc.
- <sup>6</sup> e.g., crush and landfill, clean and recycle, return to supplier, etc.

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WORKSHEET

**5**

**MATERIAL STORAGE AND  
DISPENSING PRACTICES**

Complete a separate sheet for each material identified in Worksheet 4.

Material \_\_\_\_\_

Stream Number \_\_\_\_\_

a. Describe how this material is used: \_\_\_\_\_

b. Storage container:

☐ 55 gallon drum

☐ Containers (specify volume) \_\_\_\_\_

☐ Aboveground tank

☐ Underground tank

Are tight-fitting lids provided on drums? \_\_\_\_\_

Are bung holes sealed or fitted with tight valves? \_\_\_\_\_

c. Storage area:

☐ Indoors

☐ Covered

☐ Concrete

☐ Locked

☐ Outdoors

☐ Uncovered

☐ Asphalt

☐ Unlocked

☐ Dirt

d. Delivery system:

☐ Gravity spigot

☐ Pump

☐ Funnel

☐ Other \_\_\_\_\_

e. How is material usage controlled?

☐ Stockroom attendant

☐ Access limited to designated personnel

☐ Sign-out sheet

☐ Materials readily accessible to all personnel



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WORKSHEET

**6**

**PROCESS FLOW DIAGRAM**

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WORKSHEET

**7a**

**PROCESS INFORMATION**

Worksheet 7 contains sections on the following industrial processes that generate hazardous waste:

Machining Operations

Metal Parts Cleaning & Stripping

Metal Surface Treatment & Plating Operations

Paint Application

Other: \_\_\_\_\_

Complete the appropriate sections of this worksheet that correspond to processes practiced in your plant.

**1. MACHINING OPERATIONS**

Complete for each machine:

Description of machine: \_\_\_\_\_

Identification number: \_\_\_\_\_

Type of metal working fluid used: \_\_\_\_\_

Actual water-to-fluid ratio used: \_\_\_\_\_

Size of sump: \_\_\_\_\_

Frequency of sump cleanout: \_\_\_\_\_

Is manual or hard-piped fluid addition employed? \_\_\_\_\_

How often is the machine inspected for:

hydraulic and lubrication oil leakage? \_\_\_\_\_

sump and fluid condition? \_\_\_\_\_

fluid leakage or spillage? \_\_\_\_\_

What is the reason why the machine's fluid is dumped? \_\_\_\_\_

What fluid cleaning/filtering devices are used? \_\_\_\_\_

Process Information:

How is metal working fluid removed from machines? \_\_\_\_\_

Where is it taken? \_\_\_\_\_

How often are fluid storage areas inspected for spills and leaks. \_\_\_\_\_

Quantity of fluid used per week: \_\_\_\_\_

per year: \_\_\_\_\_

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WORKSHEET

**7b**

**PROCESS INFORMATION**

(continued)

**1. MACHINING OPERATIONS (continued)**

List types and amounts of fluids used:

Type of Fluid

Annual Amount

_____	_____
_____	_____
_____	_____
_____	_____
_____	_____

Cost of waste fluid disposal: \_\_\_\_\_

\_\_\_\_\_

Cost of virgin fluid: \_\_\_\_\_

\_\_\_\_\_

Current waste management techniques: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Waste Minimization Opportunities: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Potential waste minimization savings of input materials and waste management costs: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Comments: \_\_\_\_\_

\_\_\_\_\_

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**WORKSHEET**  
**7c**

**PROCESS INFORMATION**

(continued)

**2. METAL PARTS CLEANING AND STRIPPING**

Solvent Cleaning Techniques:

Are solvents used for cleaning purposes? \_\_\_\_\_

If so, which of the following are employed?

- |  |   |
|--|---|
| <input type="checkbox"/> Vapor Degreaser<br><input type="checkbox"/> Spray Chamber<br><input type="checkbox"/> Covered Solvent Cold Cleaning Tank<br><input type="checkbox"/> Uncovered Solvent Cold Cleaning Tank | <input type="checkbox"/> Rag Wipedown<br><input type="checkbox"/> Brush Scrubbing<br><input type="checkbox"/> Other _____ |
|--|---|

<u>Solvent Chemical</u>	<u>Technique (include number &amp; sizes)</u>	<u>Annual Usage</u>

How are spent solvents managed?

- |  |   |
|--|---|
| <input type="checkbox"/> Biodegradable; dispose of in sewer<br><input type="checkbox"/> Recycled onsite<br><input type="checkbox"/> Recycled offsite | <input type="checkbox"/> Treated or incinerated onsite<br><input type="checkbox"/> Treated or incinerated offsite<br><input type="checkbox"/> Other _____ |
|--|---|

Annual Costs: \_\_\_\_\_

For onsite recycling, is residue hazardous? \_\_\_\_\_

How are used rags disposed of? \_\_\_\_\_

Annual Costs: \_\_\_\_\_

Aqueous Chemical Cleaning Techniques:

What cleansers, strippers, surfactants and detergents are used in the plant?

Types of aqueous cleaners used: \_\_\_\_\_

<u>Chemical Description</u>	<u>Active Ingredient</u>
<input type="checkbox"/> Alkaline surfactant cleaner	
<input type="checkbox"/> Alkaline detergent cleaner	
<input type="checkbox"/> Alkaline stripper	
<input type="checkbox"/> Acid cleanser	
<input type="checkbox"/> Acid stripper	

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WORKSHEET  
**7d**

**PROCESS INFORMATION**

(continued)

**2. METAL PARTS CLEANING AND STRIPPING (continued)**

Process Techniques:

- |   |                                     |
|---|-------------------------------------|
| <input type="checkbox"/> Spray chamber    | <input type="checkbox"/> Sink       |
| <input type="checkbox"/> Air-sparged bath | <input type="checkbox"/> Rag wiping |
| <input type="checkbox"/> Agitated bath    | <input type="checkbox"/> Brush      |

Type of Aqueous Cleaner

Technique (include sizes and number)

Annual Usage


**How are spent cleaners managed:**

- ☐ Biodegradable; disposed of in sewer
- ☐ Transported offsite
- ☐ Treated onsite

**Annual Costs:** \_\_\_\_\_

Abrasive Cleaning and Stripping

**Annual Costs:** \_\_\_\_\_

**Describe abrasive cleaning and stripping techniques used (e.g., blasting boxes, buffing machines, etc.)**


**How are wastes from abrasives techniques managed (e.g., dust, worn discs, etc.)** \_\_\_\_\_

**Annual Costs:** \_\_\_\_\_

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WORKSHEET  
**7e**

## PROCESS INFORMATION

(continued)

### 2. METAL PARTS CLEANING AND STRIPPING (continued)

#### Water Cleaning

Annual Costs: \_\_\_\_\_

<u>Size of Rinse Bath</u>	<u>Application<sup>1</sup></u>	<u>Continuous or Still Rinse<sup>2</sup></u>	<u>Temp.</u>	<u>Annual Usage</u>
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Are spray rinse techniques used within the plants? \_\_\_\_\_

Describe spray rinse operations: \_\_\_\_\_

Is the spray rinsing done in combination with or instead of immersion rinsing? \_\_\_\_\_

Are spent still rinses used as makeups for the process baths? \_\_\_\_\_

Is the counter-current rinsing employed at the plant? \_\_\_\_\_

Describe how it is used (Give the number of tanks in each counter-current series, the flow rates and the process chemicals rinsed from the workpieces.): \_\_\_\_\_

Water use rate for entire plant rinsing operations: \_\_\_\_\_

Is deionized water or reverse-osmosis filtered water used for rinsing/cleaning? Where? \_\_\_\_\_

Is air sparging or mechanical agitation used in the rinse baths? \_\_\_\_\_

List which technique is used in which bath: \_\_\_\_\_

- <sup>1</sup> (I.e., What process solutions are rinsed from workpieces by the bath?)  
<sup>2</sup> (Give flow rate for continuous baths.)

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WORKSHEET

7f

## PROCESS INFORMATION

(continued)

### 2. METAL PARTS CLEANING AND STRIPPING (continued)

Is the spent water recycled or reclaimed? \_\_\_\_\_

☐ settled

☐ filtered

☐ chemically classified

Is the spent water treated onsite? \_\_\_\_\_

Is the recycling or treatment residue hazardous? \_\_\_\_\_

If yes, how is it managed? \_\_\_\_\_

Waste minimization opportunities in metal parts cleaning and stripping: \_\_\_\_\_

Potential waste minimization savings of process materials and waste management costs: \_\_\_\_\_

Comments: \_\_\_\_\_

### 3. METAL SURFACE TREATMENT AND PLATING OPERATIONS

Complete a worksheet for each process tank.

Description of tank's function: \_\_\_\_\_

Identification number: \_\_\_\_\_

Size: \_\_\_\_\_

Composition of process solution: \_\_\_\_\_

Temperature: \_\_\_\_\_

Work volume (square feet of workplace surface per week): \_\_\_\_\_

Quantity of makeup solution added per week: \_\_\_\_\_

Quantity of chemicals added: \_\_\_\_\_

What chemicals are added?: \_\_\_\_\_

How much of the makeup volume is due to: \_\_\_\_\_

Replenishing dragout? \_\_\_\_\_

Replenishing evaporative losses? \_\_\_\_\_

Is deionized or reverse-osmosis filtered water used in the process baths? \_\_\_\_\_

Plant \_\_\_\_\_

Waste Minimization Assessment

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WORKSHEET

7g

## PROCESS INFORMATION

(continued)

## 3. METAL SURFACE TREATMENT AND PLATING OPERATIONS (continued)

Are dragout reduction techniques employed? \_\_\_\_\_

Which ones? \_\_\_\_\_

What is the dump schedule for the process tank? \_\_\_\_\_

Is the process line manual or automatic? \_\_\_\_\_

Is rack or barrel plating employed in the tank? \_\_\_\_\_

What is the production rate of the tank (In ft.<sup>2</sup> of workpiece surface area per week)? \_\_\_\_\_

Are baths air sparged or mechanically agitated? \_\_\_\_\_

Are personnel trained to thoroughly drain workpieces above baths before moving them to another bath? \_\_\_\_\_ Are they periodically retrained? \_\_\_\_\_

Are there spaces between process baths and their rinse tanks that allow chemicals to drip on the floor? \_\_\_\_\_

Are process baths filtered to remove particulates? \_\_\_\_\_

## 4. PAINT APPLICATION

Which paint application techniques are employed at the plant?

		<u>Volume of Work</u> (ft <sup>2</sup> of work surface coated per week)	<u>Paint Composition</u> (I.e., water based or solvent. Give solvent type. Are any lead-based paints used?)	<u>Waste Generation</u> <u>Rate</u> (Gal./Month)
Spray coating	<input type="checkbox"/>	_____	_____	_____
Dip coating	<input type="checkbox"/>	_____	_____	_____
Flow coating	<input type="checkbox"/>	_____	_____	_____
Roller coating	<input type="checkbox"/>	_____	_____	_____
Curtain coating	<input type="checkbox"/>	_____	_____	_____
Electro-coating	<input type="checkbox"/>	_____	_____	_____
Brush coating	<input type="checkbox"/>	_____	_____	_____
Powder coating	<input type="checkbox"/>	_____	_____	_____
Radiation curable coating	<input type="checkbox"/>	_____	_____	_____



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**WORKSHEET**  
**7h**

**PROCESS INFORMATION**

(continued)

**4. PAINT APPLICATION (continued)**

Small part paint application:

Tumbling ☐ \_\_\_\_\_

Barrelling ☐ \_\_\_\_\_

Centrifuging ☐ \_\_\_\_\_

What size paint containers are purchased? \_\_\_\_\_

How is leftover paint waste in containers managed? \_\_\_\_\_

What measures are taken to control/manage overspray and drippings? \_\_\_\_\_

What temperatures are bake ovens run at? \_\_\_\_\_

**5. MISCELLANEOUS**

Are any metal oxide wastes generated in welding or soldering operations in your plant? \_\_\_\_\_

Note: If so, they must be managed as hazardous waste.

Are any hazardous fluxes used in welding or soldering operations? \_\_\_\_\_

How are the above wastes managed? \_\_\_\_\_

**6. OTHER PROCESSES THAT GENERATE HAZARDOUS WASTE**

Process	Type of Waste	Annual Amount	Management Method	Annual Cost of Management

Potential Source Reduction and Recycling Opportunities. \_\_\_\_\_

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**WORKSHEET**  
**8**

**DOCUMENTATION AVAILABLE**

Process Line: \_\_\_\_\_

Operation Type:

☐

Continuous

☐

Discrete

☐

Batch or Semi-Batch

☐

Other \_\_\_\_\_

Document	Status					
	Complete? (Y/N)	Current? (Y/N)	Last Revision	Used in this Report (Y/N)	Document Number	Location
Process Flow Diagram						
Material/Energy Balance						
Design						
Operating						
Flow/Amount Measurements						
Stream						
Analyses/Assays						
Stream						
Process Description						
Operating Manuals						
Equipment List						
Equipment Specifications						
Piping & Instrument Diagrams						
Plot and Elevation Plan(s)						
Work Flow Diagrams						
Hazardous Waste Manifests						
Emission Inventories						
Pretreatment Records						
Sewer Use Permit						
Annual/Biennial Reports						
Environmental Audit Reports						
Permit/Permit Applications						
Batch Sheet(s)						
Materials Application Diagrams						
Product Composition Sheets						
Material Safety Data Sheets						
Inventory Records						
Operator Logs						
Production Schedules						







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WORKSHEET

**11a**

**INDIVIDUAL WASTE STREAM  
GENERATION AND CHARACTERIZATION**

- Waste Stream Name/ID: \_\_\_\_\_ Stream Number \_\_\_\_\_  
Process Unit/Operation \_\_\_\_\_
- Waste Characteristics (attach additional sheets with composition data, as necessary.)  
☐ gas    ☐ liquid    ☐ solid    ☐ mixed phase  
 Density, lb/cuft \_\_\_\_\_ High Heating Value, Btu/lb \_\_\_\_\_  
 Viscosity/Consistency \_\_\_\_\_  
 pH \_\_\_\_\_, Flash Point \_\_\_\_\_; % Water \_\_\_\_\_
- Waste Leaves Process as:  
☐ air emission    ☐ waste water    ☐ solid waste    ☐ hazardous waste
- Waste Generation is:  
☐ continuous \_\_\_\_\_  
☐ periodic \_\_\_\_\_ length of period: \_\_\_\_\_  
☐ sporadic (irregular occurrence)  
☐ non-recurrent
- What Determines It To Be A Waste?  
☐ Chemical Analysis  
☐ Process Type  
☐ Industry Type  
☐ EPA Chemicals List
- What Could Eliminate This Waste Generation?  
☐ Improved Operations  
☐ Material Substitutions  
☐ Other: \_\_\_\_\_
- Generation Rate  
 Annual \_\_\_\_\_ lbs per year  
 Maximum \_\_\_\_\_ lbs per \_\_\_\_\_  
 Average \_\_\_\_\_ lbs per \_\_\_\_\_  
 Frequency \_\_\_\_\_ batches per \_\_\_\_\_  
 Batch Size \_\_\_\_\_ average \_\_\_\_\_ range

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**WORKSHEET**  
**11b**

**INDIVIDUAL WASTE STREAM  
GENERATION AND CHARACTERIZATION**

(continued)

Waste Stream \_\_\_\_\_

**6. Waste Origins/Sources**

Fill out this worksheet to identify the origin of the waste. If the waste is a mixture of waste streams, fill out a sheet for each of the individual waste streams.

Is the waste mixed with other wastes? ☐ Yes ☐ No

Is waste segregation possible? ☐ Yes ☐ No

If yes, what can be segregated from it? \_\_\_\_\_

If no, why not? \_\_\_\_\_

How is the waste generated?

- ☐ Formation and removal of an undesirable byproduct compound
- ☐ Removal of an unconverted input material
- ☐ Depletion of a key component (e.g., drag-out)
- ☐ Equipment cleaning waste
- ☐ Obsolete input material
- ☐ Spoiled batch and production run
- ☐ Spill or leak cleanup
- ☐ Evaporative loss
- ☐ Breathing or venting losses
- ☐ Other: \_\_\_\_\_

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WORKSHEET

**11c**

**INDIVIDUAL WASTE STREAM  
GENERATION AND CHARACTERIZATION**

(continued)

Waste Stream \_\_\_\_\_

**7. Management Method**

Leaves site in

☐

bulk \_\_\_\_\_

☐

roll off bins \_\_\_\_\_

☐

55 gal drums \_\_\_\_\_

☐

other (describe) \_\_\_\_\_

Disposal Frequency \_\_\_\_\_

Applicable Regulations<sup>1</sup> \_\_\_\_\_

Regulatory Classification<sup>2</sup> \_\_\_\_\_

Managed

☐

onsite

☐

offsite

☐

commercial TSDR \_\_\_\_\_

☐

own TSDR \_\_\_\_\_

☐

other (describe) \_\_\_\_\_

Recycling

☐

direct use/re-use \_\_\_\_\_

☐

combusted for energy content \_\_\_\_\_

☐

redistilled \_\_\_\_\_

☐

other (describe) \_\_\_\_\_

Reclaimed material returned to site?

☐

Yes

☐

No

☐

used by others

residue yield \_\_\_\_\_

How is the residue managed? \_\_\_\_\_

**Note<sup>1</sup>** list federal, state & local regulations, (e.g., RCRA, TSCA, etc.)

**Note<sup>2</sup>** list pertinent regulatory classification (e.g., RCRA - Listed K011 waste, etc.)

**TSDR** - Treatment, Storage, Disposal or Recycling Facility



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WORKSHEET

**11d**

**INDIVIDUAL WASTE STREAM  
GENERATION AND CHARACTERIZATION**

(continued)

**Waste Stream** \_\_\_\_\_

**-7. Management Method (continued)**

**Treatment**

- ☐ biological \_\_\_\_\_
- ☐ oxidation/reduction \_\_\_\_\_
- ☐ incineration \_\_\_\_\_
- ☐ pH adjustment \_\_\_\_\_
- ☐ precipitation \_\_\_\_\_
- ☐ solidification/stabilization \_\_\_\_\_
- ☐ other (describe) \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_
- \_\_\_\_\_

**Which final disposal is involved in management of the waste or its residue?**

- ☐ landfill \_\_\_\_\_
- ☐ pond \_\_\_\_\_
- ☐ lagoon \_\_\_\_\_
- ☐ deep well \_\_\_\_\_
- ☐ ocean \_\_\_\_\_
- ☐ other (describe) \_\_\_\_\_
- \_\_\_\_\_

**What is the projected date for phasing out this disposal practice?** \_\_\_\_\_

**Costs as of** \_\_\_\_\_ **(quarter and year)**

Cost Element:	Unit Price \$ per _____	Reference/Source:
Onsite Storage & Handling		
Pretreatment		
Container		
Transportation Fee		
Disposal Fee		
Local Taxes		
State Tax		
Federal Tax		
<b>Total Disposal Cost</b>		

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WORKSHEET

**12**

**WASTE STREAM SUMMARY**

Attribute	Description <sup>1</sup>								
	Stream No. _____		Stream No. _____		Stream No. _____		Stream No. _____		
Waste ID/Name:									
Source/Origin									
Hazardous Component									
Annual Generation Rate (units _____)									
Overall									
Component(s) of Concern									
Cost of Disposal									
Unit Cost (\$ per: _____)									
Overall (per year)									
Method of Management <sup>2</sup>									
Priority Rating Criteria <sup>3</sup>	Relative Wt. (W) <sup>4</sup>	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W	Rating (R)	R x W
Regulatory Compliance									
Treatment/Disposal Cost									
Potential Liability									
Waste Quantity Generated									
Waste Hazard									
Safety Hazard									
Minimization Potential									
Potential to Remove Bottleneck									
Potential By-product Recovery									
Sum of Priority Rating Scores		$\Sigma(R \times W)$		$\Sigma(R \times W)$		$\Sigma(R \times W)$		$\Sigma(R \times W)$	
Priority Rank									

- Notes:**
1. Stream numbers, if applicable, should correspond to those used on process flow diagrams.
  2. For example, sanitary landfill, hazardous waste landfill, onsite recycle, incineration, combustion with heat recovery, distillation, dewatering, etc.
  3. Rate each stream in each category on a scale from 0 (none) to 10 (high).
  4. A very important criteria for your plant would receive a weight of 10; a relatively unimportant criteria might be given a weight of 2 or 3.

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WORKSHEET

13a

WASTE MINIMIZATION OPTIONS

Source reduction and recycling options for each metal fabrication industrial process are listed below (and discussed in detail earlier in this report). Select those that appear most promising for your plant, and enter these on Worksheet 13. Remember that source reduction options frequently offer both environmental and economic advantages over recycling.

**PROCESS**

Machining Operations

**OPTIONS** (Check those that appear promising for your plant.)

Source Reduction:

Preventing Metal Working Fluid Contamination ☐

Optimal Fluid Selection ☐

Periodic or Continuous Filtration ☐

Demineralized Water Use ☐

Fluid Concentration Control ☐

Material Substitution: Synthetic Fluids ☐

Other \_\_\_\_\_ ☐

Recycling:

Filtration ☐

Skimming ☐

Coalescing ☐

Hydrocycloning ☐

Centrifugation ☐

Pasteurization ☐

Downgrading and Reusing Fluids ☐

Other \_\_\_\_\_ ☐

Metal Parts Cleaning and Stripping

Source Reduction:

General Operating Procedures ☐

Process Controls ☐

Operator Training ☐

Drainage Techniques ☐

Storage and Distribution Measures ☐

Other \_\_\_\_\_ ☐

Solvents

Vapor Degreaser Use ☐

Covered Immersion Tanks ☐

Drainboard Installation ☐

Other \_\_\_\_\_ ☐

Material Substitution

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## WORKSHEET

**13b**

## WASTE MINIMIZATION OPTIONS

(continued)

## Metal Parts Cleaning and Stripping

**Source Reduction (continued):**

## Aqueous Cleaners

## Sludge Removal

## Tank Lids

**Other**

## Abrasives

## Use of Water-Based Binders

## Liquid Spray Abrasives

## Precleaning of Workpiece

**Other**

### Recycling:

## Solvents

## Filtration

## Distillation

## Abrasives

## Reusable Blasting Media

**Other**

**Source Reduction:**

## Process Modifications

## Dragout, Spill and Leak Reduction

## Efficient Drainage

### Viscosity and Surface Tension Control

**Other**

### Bath Solution Waste Reduction

## Rinse System Design

## Still Finee Design

## Counter Current Rinsing

## Efficient Drainage

### Use of No-Rinse Coatings

**Other**

## Solid Waste Management

## Metal Surface Treatment and Plating

[illegible]

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WORKSHEET

**13d**

**WASTE MINIMIZATION OPTIONS**

(continued)

**Good Operating Practices**

**Material Handling Improvements**

**Waste Stream Segregation**

**Loss Prevention Practices**

**Preventive and Corrective Maintenance**

**Personnel Practices and Training**

**Management Initiatives**

**Employee Training**

**Employee Incentives**

**Procedural Measures**

**Documentation and Tracking**

**Storage**

**Other Good Operating Practices**

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## References

- Baumeister, T., ed. 1967. *Standard Handbook for Mechanical Engineers*. McGraw-Hill. 1967. pg. 13-71.
- Brewer, G. 1980. *Calculations of Painting Wasteloads Associated with Metal Finishing*. USEPA, Cincinnati, Ohio.
- Campbell, M., and Glenn, W. 1982. *Profit from Pollution Prevention - a Guide to Industrial Waste Reduction and Recycling*. Pollution Probe Foundation. Toronto, Ontario.
- Centrico Inc. Fall 1986. "How Borg-Warner Automotive Recycles Coolants". *Centrifacts*. No. 49.
- DHS. 1989. *Waste Audit Study: Fabricated Metal Products Industry*. Prepared by Jacobs Engineering Group for Alternative Technology Section, Toxic Substances Control Division, California Dept. of Health Services.
- Dowd, P. 1985. "Conserving Water and Segregating Waste Streams." *Plating and Surface Finishing*. 72(5): 104-8.
- Durney, L.J. ed. 1984. *Electroplating Engineering Handbook*. 4th Edition. Van Nostrand Reinhold. New York. 1984.
- EERC. 1988. *Guide to Oil Waste Management Alternatives*. Energy and Environmental Research Corporation, Robert H. Salvesson Associates, and Evergreen Oil, Inc.
- Foss Plating. August 1988. Personal Communication. Santa Fe Spring, CA.
- Hayes, M.F. December 1987. "Chlorinated CFC Solvent Replacement in the Electronics Industry. The Terpene Hydrocarbon Alternative." *Proceedings of the 3rd Annual Hazardous Materials Management Conference West*. Long Beach, CA.
- Huisingh, D., Hilger, H. Thesen, S. and Martin, L. Proven Profit from Pollution Prevention. Institute for Local Self-Reliance. Washington, D.C.
- Jacobs Engineering Group. December 1986. *Case Studies of Minimization of Cyanide Waste from Electroplating Operations*. USEPA, Contract No. 68-01-7053, Task #46.
- Kirk-Othmer: *Encyclopedia of Chemical Technology*. 1981. Third Edition. Volume 15. John Wiley & Sons, New York.
- Kohl, J., P. Moses, and B. Triplett. 1984. *Management Recycling Solvents: North Carolina Practices Facilities, and Regulations*. North Carolina State University, Raleigh, N.C..
- Krofchak, D., and Stone, J.N. 1975. *Science and Engineering for Pollution-Free Systems*. Ann Arbor Science Publishers Inc. Ann Arbor, Michigan.
- Lorton, G. April 1988. *Journal of Air Pollution Control Association*. Vol. 38, No. 4. pg. 424.
- Metals Handbook*. Ninth Edition. Volume 5. Surface Cleaning, Finishing, and Coating. March 1987. American Society of Metals Park, Ohio.
- Normandy Refinishers. March 1988. Personal Communication. Pasadena, CA.
- Pinkerton, H.L. and Graham, K.A. 1984. "Rinsing." *Electroplating Engineering Handbook*. Fourth Edition. Durney, L.J., editor. Van Nostrand Reinhold Co., New York. pg. 691-709.
- Pollution Prevention Tips. 1985. (a) "Water Conservation for Electroplaters: Rinse Tank Design"; (b) "Water Conservation for Electroplaters: Counter-Current Rinsing"; (c) "Water Conservation for Electroplaters: Rinse Water Reuse." *Pollution Prevention Pays Program*, North Carolina Department of Natural Resources and Community Development.
- Porter, C.L. December 1988. *Minimization of Metal Working Fluid Wastes*. Master of Engineering Thesis. University of Louisville, Speed Scientific School, Department of Chemical Engineering. Thesis Advisor: Marvin Fleischman, Professor, Chemical Engineering.
- PRC Environmental Management, Inc. May 1988. *Waste Audit Study: Metal Finishing Industry*. California Dept. of Health Services.
- Report to Congress. 1986. *Waste Minimization Issues and Options*, Volume 2, Appendix B: Process studies. Prepared by Jacobs Engineering Group for USEPA, Office of Solid Waste, Waste Treatment Branch. EPA/530-SW-86-042.
- Schaffer, G. February 1978. "Recycling Coolant Reduces Cost." *American Machinist*.
- Schwartz, S.I. October 1986. "Recycling of Hazardous Waste Solvents: Economic and Policy Aspects." *Solvent Waste Reduction Alternatives Symposia Conference Proceedings*. Los Angeles, CA. Sponsored by California Department of Health Services.
- Sluhan, W.A. *The Application of High Speed, Disc Bowl*

- Centrifuges to Water Miscible Cutting and Grinding Fluids. Master Chemical Corporation, Perrysburg, Ohio.
- Smith, C. November 1981. "Trouble Shooting Vapor Degreasers." Product Finishing.
- USEPA. 1980. Development Document for Effluent Limitations: Guidelines and Standards for the Metal Finishing Industry. Environmental Protection Agency, Office of Water Regulations and Standards. EPA-440-1-80-091A.
- USEPA. 1982. Control and Treatment Technology for the Metal Finishing Industry: In-Plant Changes.
- USEPA. April 1988. Waste Minimization Opportunity Assessment Manual. U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, Cincinnati, EPA/625/7-88/003.
- Zabik, M.J., Wildman, J.L., Moran, C. May 1987. Unique Methods for Extending the Life of Synthetic Metalworking Fluids in a Manufacturing Environment - A Case Study. ASLE Paper No. 87-AM-6B-3, Anaheim, CA. pg. 1-3.



## **Appendix A**

### **FABRICATED METAL PRODUCT FACILITY ASSESSMENTS: CASE STUDIES OF PLANTS**

In 1988 the California Department of Health Services commissioned a waste minimization study (DHS 1989) that included assessments of three fabricated metal products facilities. The objectives of the study were to:

- Gather site-specific information concerning the generation, handling, storage, treatment, and disposal of hazardous waste;
- Evaluate existing waste reduction practices;
- Develop recommendations for waste management through source reduction, treatment, and recycling techniques; and
- Assess costs/benefits of existing and recommended waste reduction techniques.

In addition, the results of the waste assessments were used to prepare waste minimization assessment worksheets to be completed by other facilities in a self-audit process.

The first steps in conducting the assessments were the selection of the plants, and contacting the plants to solicit

voluntary participation in the audit study. Plant selection emphasized small businesses which generally lack the financial and/or internal technical resources to perform a waste reduction audit. One relatively large plant was also selected for study because it offered the opportunity to evaluate a wide variety of operations, as well as a number of in-place waste reduction measures. A total of three plants was audited.

This Appendix section presents both the results of the assessments of the plants here identified as A, B and C and the potentially useful waste minimization options identified through the assessments. Also included are the practices already in use at the plants that have successfully reduced waste generation from past levels. During each of the plant audits, the audit team observed operations; inspected waste management facilities; interviewed the plant manager, environmental compliance personnel, and operations supervisors; and collected records pertinent to waste generation and management.

## Plant A Waste Minimization Opportunity Assessment

Plant A manufactures metal laboratory furniture. It employs 20 production personnel and 10 administrative staff. Its operations, which correspond to SIC category 2522, include sheet metal cutting, shearing, notching, punching, forming, cleaning, welding and painting. These operations are used in the manufacture of base cabinetry, wall cases and fume hoods.

The plant was opened in 1972, although much of the equipment is considerably newer. The plant currently produces 3500 units of furniture per year, with annual revenues of \$3 million.

### PROCESS DESCRIPTION

The plant utilizes 30 to 40 tons per year of nongalvanized, unfinished cold rolled plate steel in its processes. The steel plate is first sheared to size, then punched on a turret punch press, and formed on multiple or single stage brake presses. The workpieces are then assembled using spot welding, and finished by grinding and sanding operations. Next, the workpieces are immersed in a series of cleaning tanks that include the following processes:

- High pH sodium hydroxide caustic bath. 1000 lbs of Amclene 17 sodium hydroxide are used each year to produce a 50 percent caustic solution;
- Water bath and hose rinse;
- Acid phosphatizing bath, employing Americoat 105 iron phosphate;
- Water rinse;
- Rust inhibitor bath. A pH-adjusted phosphoric acid solution is made up, using Amseal NC 155 A and B.

Spent caustic and acid cleaning solutions are discharged to the sewer, after pH adjustment if necessary. The pH must be between 6 and 10 before wastes can go into the sewer. The acid baths are normally very close to pH 6. The caustic bath often needs adjustment, for it ranges in pH from 12 to 14. The sludge buildup at the bottom of the cleaning tanks must periodically be shovelled out. It is then dried and disposed of as nonhazardous waste.

### INPUT MATERIALS

Input materials purchases for plant processes include nongalvanized, unfinished cold rolled steel, paint (mostly water-based acrylic enamel), wash solvent and rags for equipment and workpiece wipedown, Amclean 17 (pH 14)

caustic bath, Number 105 phosphatizer (containing pH 5 sulfuric acid), and Amseal biodegradable final rinse (all from American Research Products).

### WASTE MINIMIZATION

Waste streams generated by the plant include solvent wastes and paint sludge. Until 1986, the plant generated twelve 55-gallon drums per year of solvent and paint waste, which were picked up for offsite recycling at a cost to the plant of \$80 per drum. When the recycler raised its price to \$800 per drum, the plant decided to implement major waste minimization methods, the most dramatic of which was a change from solvent based paints to water based paints with very small amounts of solvent in them.

The acrylic enamel water based paints that have been adopted are oven baked after application to produce a durable surface comparable to that of the solvent based paints formerly used. Dried wastes from the water based acrylic have been shown to be nonhazardous in fish biopsy tests. The water based paints have a shelf life considerably longer than solvent paints, which spoil by the time they are 6 months old. This additional shelf life results in less paint being thrown away, and thus also is responsible for minimization of wastes. The change in paints has reduced the plant's total drummed hazardous wastes by 75% - from 12 to three 55-gallon drums per year. Changing paints did require a change to electrostatic spray equipment, however, which cost \$4500. Operator training time to learn to use the new equipment was minimal. Solvent is still used in the spray process to purge paint lines, and it is this operation that produces much of the three 55-gallon drums per year of spent solvent and sludge. Wash solvent is also used to wipe down workpieces. The commercial offsite recycler takes the drummed wastes, charging \$40 to recycle a drum of liquid solvent, but \$12.50 per gallon to handle sludge.

The water based paints are slightly more expensive than the solvent based ones (\$17/gal as compared to \$14), and cover only 100 ft<sup>2</sup>/gal, whereas the solvent-based paints covered 125 ft<sup>2</sup>. But the solvent paints had to be baked at 380°F for thorough drying and a durable finish, whereas the water based paints only need a temperature of 280°.

The paints are applied in a spray booth. Overspray is drawn into a closed loop waterfall; the paint sludge is separated out and the water is recycled.

Paint sludge is air dried in an open tank and discarded as nonhazardous waste. Empty paint containers are rinsed out (into the drain) and are also disposed of as nonhazardous waste.

Plans for the future include reducing the shop's water

use by replumbing the shop so as to route cooling water from the spot welder into the rinse tanks. The shop could also save water, and reduce the wastes being drained into the sewer, by using its rinse baths as makeup water for the caustic and acid cleaning baths.

### **Plant B Waste Minimization Opportunity Assessment**

Plant B is a machine shop that performs contract work for aerospace companies, computer firms and other businesses. The company was founded in 1969, although they have been in their present location only 2 years. The plant employs a total staff of 80 to 90 personnel, with annual revenues of \$6 million.

The shop machines all types of metals, from extremely tough inconel to mild steel. The shop specializes in high quality, close tolerance work, has made parts for the space shuttle, and uses computer controlled, automatic machining equipment for most of its work.

### **PROCESS DESCRIPTION**

A typical workpiece starts out in the shop as bar stock, and is then sawed, turned on a lathe, milled and ground to the proper shape. If plating, anodizing, etc. is required, the workpiece is sent offsite for these operations. Upon its return to the plant, it is inspected, deburred and shipped.

Parts are cleaned using 1,1,1 trichloroethane (TCA). This is the only solvent employed in the shop. It is furnished, and maintained, by a commercial solvent recycler. Most of the solvent is used in open immersion tanks, in which the manufactured computer parts are cleaned. Computer parts make up about 15% of the shop's volume.

### **INPUT MATERIALS AND WASTE STREAMS**

The plant receives up to 240 gallons of TCA per week, and produces an average of 800 gallons of solvent waste in 80 days.

The only coolant used by the shop in its machining equipment is Cincinnati 1011, a water based coolant containing some oil. Synthetic coolants were tried 5 years ago, with poor results, including removal of paint from the machines. The Cincinnati coolant is diluted with water to ratios of 20:1 to 40:1 depending upon the application. Tap water is used for this dilution. 4000 gallons of diluted coolant are disposed of every year.

The shop uses 300 to 400 gal/yr of light hydraulic oil in its machines and a small amount of kerosene (less than 55 gallons every 2 years) as a manual cutting oil for machining of tooling for the computer-run machines. The shop buys mostly aluminum, steel and stainless steel for its work, and a small amount of carbide for making cutting tools.

### **WASTE MINIMIZATION**

Plant B is in the process of converting to a deionized (DI) water system for dilution of the machine coolant. The minerals in tap water have caused various problems, including difficulties in mixing, and uneven concentrations of chemicals to the cutting tools. DI water use is expected to lengthen tool life as well as to reduce bacteria growth and lengthen the coolant life.

The plant used to manage its spent machine coolant by draining its own sumps and storing the waste onsite until it was hauled off for disposal. Several years ago, accidental contamination of a truckload of waste coolant with TCA resulted in disposal costs to the plant of \$20,000 instead of the expected cost of \$500.

The danger of contamination is greatly lessened today by having the haulers pump the waste coolant directly from the machine sumps, instead of allowing it to sit around in drums. The plant is considering using an offsite "Trimsol" coolant management service in the future that includes periodic inspections of coolant contaminant concentrations, draining of the sumps when necessary and replacement with recycled coolant. The periodic inspection and testing will prevent degradation of the coolants to the point where they cannot be recycled.

Spent solvent (800 gallons every 80 days) is taken by a commercial offsite recycler who currently pays the plant \$1.50 for each gallon of recyclable solvent, but charges for disposing of all still bottoms generated. The recycled solvent is sold back to the plant at \$4 per gallon.

The most promising area for future waste minimization appears to be solvent use reduction. Plant B uses approximately 10,000 gallons of 1,1,1 trichloroethane per year, most of which is employed in open immersion troughs in which workpieces are dipped and hand scrubbed after buffing operations. The evaporation rate is quite high from these troughs, and less than 4000 gal/yr of solvent are recovered for recycling. Besides putting substantial VOC's into the air, the open trough system is expensive. Recycled solvent costs the plant \$4/gal, while it receives only about \$1.50 for each gallon it gives to the recyclers. Thus, current solvent costs run \$40,000/yr minus the \$6000 for recyclable solvent, adding up to \$34,000/yr.

There are several possibilities for reducing the plant's evaporative solvent losses. One method that would incur moderate rather than high costs would be to install sliding covers on the two solvent troughs that could be operated automatically with a foot pedal or switch, along with a strong agitating device to remove the buffing grit - either a jet manifold or an ultrasonic generator - and a drainage shelf. The cover would normally be kept closed. When

there was work to be cleaned, the cover would be opened, the work would be put in the tank, the cover closed again, and the jets or the ultrasonic generator turned on to agitate the solvent and provide cleaning action. If the system operated successfully, little or no hand scrubbing would be necessary. The operator would be freed to perform other tasks while the work is being cleaned. When the cleaning is completed, the operator would open the tanks, remove the work from the solvent and place it on the drainage shelf to dry (the shelf would be installed inside the tank). The operator would then place new work into the solvent and close the tank, returning later to remove the dry work from the drainage shelf and the solvent. The only times that the sliding cover would be opened, allowing solvent vapors to escape from the tanks, are when the operator is either adding workpieces to the tank, transferring them to the drainage shelf, or removing them.

While the proposed system appears promising, it must be mentioned that the plant manager felt that much of the soil on workpieces could not be removed by high pressure jets, but required hand scrubbing. The jets might also increase the solvent evaporation rate, raising rather than lowering materials costs. The plant has already experimented with using ultrasonic cleaners for removing buffing grit. Initial results were not encouraging for removing very fine grit particles, indicating the need for more powerful agitation.

### Plant C Waste Minimization Opportunity Assessment

Plant C is a decorative chrome electroplating shop (SIC 3471) that employs approximately 50 personnel, of which 45 are production staff and 5 are administrative staff. The company has been in business since 1948, while the present plant was opened in 1968. The machines presently used were installed in 1974.

#### THE PLATING LINE

An "automatic" plating line is employed in the plant, in which computer controlled cranes advance the workpiece through the plating lines, immerse them in the baths, remove them and let them drain. The plating line includes nickel undercoat baths and a chrome topcoat bath, and consists of the following steps:

##### Preprocessing

- Soak cleaning. High pH caustics are used to remove grease and oil from the workpiece.
- Running rinse. Tap water is used, at a flow of 3 gal/min.
- Pickling. Hydrochloric acid descaling solutions are used.

- Running rinse. Same rinse tank as above.
- Rust preventative. This is a proprietary, nitrate based bath that is considered nonhazardous by the plant management.

#### Polishing

- Belt sanding and buffing. Dust produced is nonhazardous and disposed of as municipal waste.

#### Cleaning

- Vapor degreasing or solvent wipedown. 1,1,1-trichloroethane is used in the vapor degreaser, while a proprietary Stoddard-type solvent is employed for wipedown.
- Soak cleaning. Two baths, employing proprietary cleaners.
- Water rinse. Tap water is used. This is the final, least clean stage of counterflow system A (a three part system). After use, water is pumped to treatment system and then disposed of down drain.
- Electrocleaner. Caustic with a reverse electric current is employed.
- Water rinse. Second stage of counterflow system A.
- Sour dip. 10% muriatic acid solution.
- Water rinse. Second, least clean stage of counterflow system B (a two-stage system). This system uses cooling water from a bank of rectifiers. At present, spent water is pumped to treatment system and then disposed of, but in the future, it will be used as makeup for the nickel bath.

#### Nickel Plating

- Semi brite nickel. Composition: 30 oz/gal nickel sulfate, 5 oz/gal nickel chloride, 7 oz/gal boric acid, plus small quantities of organic brighteners. Total nickel metal content in the salts, 8 oz/gal. The nickel baths are maintained at 140°F to 150°F.
- Bright nickel. 35 oz/gal nickel sulfate, 14 oz/gal nickel chloride, 7 oz boric acid, and saccharine. Total nickel metal content in the salts: 10 oz/gal.
- Proprietary nickel dip. A proprietary "microporous" nickel solution that gives

porosity to the plating layer, to inhibit corrosion. Uses the same nickel compound and boric acid concentrations as the bright dip.

### **Cleaning**

- Standing nickel dragout. A deionized (DI) water still rinse that is used as makeup for the bright nickel dip. 300 to 400 gallons per day of the rinse is added to the bright nickel bath.
- Water rinse. First stage of counterflow system B. Any nickel remaining on the workpiece is precipitated in this bath.

### **Chrome Plating**

- Chrome bath. 30 oz/gal chromic acid.
- 5 stage counterflow rinse system C. DI water at a flow rate of 3 gal/min and a temperature of 105°F is used. Water from the fifth, least clean stage of the system is employed as makeup water for the chrome bath. An evaporator is attached to the chrome bath so that sufficient water from the plating solution is evaporated to allow the makeup water to be added. This closed loop prevents virtually all of the chromium from reaching the treatment system and being disposed of either in the effluent to the sewer, or in the dried sludge.

After the workpieces go through the 5-stage rinse, they are allowed to dry, are inspected, and if acceptable, packaged and shipped.

### **INPUT MATERIALS AND PRODUCTS**

Input materials to the plating processes include 3000 lb/month of soak and electrocleaners, which contain caustics that are neutralized in the plant's treatment system, 500 gal/mo of muriatic acid, up to 1500 lb/year nickel chloride and 1000 lb/year nickel sulfate, 150 gal/mo of 1,1,1-trichloroethane, 200 gal/yr of Stoddard solvent, 1000 lb/yr of chromic acid, and 4 million gal/yr of water.

The plant currently produces about 100,000 ft<sup>2</sup>/mo of plated surfaces, and receives just under \$2 million per year in revenue. 1.8 million gal/yr of treated wastewater is released to the sewer; 2.2 million gal/yr is evaporated.

### **WASTE STREAMS AND TREATMENT SYSTEM**

Waste streams from the plating lines include cleaning solution wastes, pickling wastes, rinse water, 1,1,1-trichloroethane (TCA) from the vapor degreaser, and spills and leaks from the baths. The TCA wastes are sent back to the supplier (Rho Chem), who recycles them and returns the reconstituted solvent. The other wastes from the plating line are sent to the plant's treatment system.

In the treatment system, caustic cleaners are mixed with acid pickling wastes. Additional caustic is added to adjust the pH to 9.5, and flocculants are added for settling of the precipitates and solids. Plant personnel have found that a pH of 9.5 provides the best settling. The treatment effluent is released to the sewer, while the sludge is filtered and dried using heaters.

The effluent typically contains 0.5 to 1 ppm nickel. Chrome levels are usually much lower, and often non-detectable, because the chrome line is a closed loop system. Chrome that does reach the treatment system is mainly from spills. Nickel levels are expected to also drop once the nickel line is made closed loop.

The sludge is filter pressed and heated to evaporate its water. The dried filter cake typically contains 500 to 700 ppm chrome, and 70,000 ppm nickel (nickel levels will drop once a closed loop nickel line is implemented). Most of the nickel is in the form of nickel hydroxide. The dried filter cake is shipped to World Resources Corporation in Arizona for recovery of the metals.

### **WASTE MINIMIZATION MEASURES**

The plant has been quite innovative in instituting a variety of waste minimization measures throughout its processes. These measures include:

- Increased dwell time for parts being drained above process baths;
- Counterflow rinses;
- Closed loop process line;
- Deionized water use;
- Process tank filtration;
- Elimination of cyanide use;
- Process water recycling;
- Solvent recycling;
- Filter cake recycling; and
- Process line design.

### **Increased Dwells**

The computerized automatic plating line was reprogrammed to increase dwell time for better drainage of workpieces after removal from process baths, and to decrease dragout. The automatic equipment takes 6 seconds to remove a workpiece from a bath. It used to be programmed to allow 3 additional seconds of drainage after removal of the workpiece; the dwell has now been increased from 3 to 10 seconds.

### ***Counterflow Rinses***

Several counterflow rinses are used in the process line, in order to reduce rinse water use. A three-stage and a two-stage counterflow rinse is used in the nickel process, and a five-stage counterflow is employed in the chrome line.

### ***Closed Loop Process Line***

The entire chrome line, consisting of a chrome bath and a 5-stage counterflow rinse system, is a closed loop system. Overflow from the last (least clean) stage of the counterflow rinse is fed back into the chrome bath. This flow amounts to about 3 gal/min. The chrome bath does not overflow because an evaporator vaporizes water from the bath at a rate equal to the inflow.

This setup ensures that almost all of the chrome dragged out of the chrome bath by the workpieces and into the rinses eventually finds its way back into the chrome bath, and not down the sewer. Besides being environmentally beneficial in that it prevents most chrome wastes from entering the environment, this practice also offsets the additional capital and operating (mostly energy) costs in three different ways: 1) lower sewer surcharges; 2) lower water use charges; and 3) lower treatment system maintenance expenses, since considerably less water goes into the treatment system.

The nickel line has a smaller closed loop, although the plant management plans to modify it into a closed loop similar to that of the chrome line. At present, the bright nickel, proprietary nickel and standing nickel dragout tanks form a closed loop. Workpieces emerging from the proprietary nickel tank (the last nickel plating bath) are immersed in the standing dragout tank. When this still rinse is dirty, it is used as makeup for the bright nickel tank. The bright nickel tank is kept at a temperature of 140 to 150°F, and as a result, 300 to 400 gal/day of water evaporates from it, and is made up from the still rinse.

### ***Deionized Water Use***

DI water is used to replenish the standing nickel dragout bath and the 5 stage chrome line counterflow loop systems. If DI water was not used, impurities would build up much faster than they do. At present, the chrome line closed loop has been in operation for 2 years, and the chrome bath has not yet needed draining and replenishing.

### ***Process Tank Filtration***

The purity and long life of the process baths is due not only to use of DI water, but also to other factors, one of which is their continuous filtration. The process baths are filtered at rates of between 15 and 20,000 gal/hr. The baths are 3500 gallons in volume.

### ***Elimination of Cyanide Use***

The plant used to use cyanide based plating and stripping solutions, and had to dispose of 1000 gallons of 8 oz/gal cyanide solution every 60 days. The plant replaced these solutions with noncyanide based chemicals. The nickel process uses nickel sulfate and chloride, and the cleaning and stripping is done with caustic, muriatic acid and electrocleaning techniques.

### ***Process Water Recycling***

As mentioned above, spent water from some of the rinse tanks is used as makeup water for plating baths. In addition to this recycling, the rinsewater itself is recycled water in some of the systems. Rinse water in counterflow rinse system A comes from cooling water in the vapor degreaser and boiler cooling pumps. Water in counterflow rinse system B is taken from cooling water for a bank of rectifiers.

### ***Solvent Recycling***

Spent 1,1,1-trichloroethane from the vapor degreaser is recycled offsite by Rho Chem, who supplies the plant with reconstituted solvent.

### ***Filter Cake Recycling***

Dried filter cake from the treatment system filter presses and drying ovens is sent to the World Resource Corporation in Arizona for recovery of the nickel and chrome it contains.

### ***Process Line Design***

The process tanks are installed butted up tightly against each other to minimize spills onto the floor due to dragout. Separate spill collection systems are included for the nickel line and the chrome line, so that the different chemicals in any spills maybe segregated from each other if necessary.

### ***Future Waste Minimization Plans***

The plant is considering implementing additional waste segregation measures. Some of the process rinse water, for instance, remains clean enough to be disposed of directly into the sewer without treatment. It is now treated, but if this practice were eliminated, it would cut down on sludge and filter cake production.

Wastewater from bulk pickling processes could also be disposed of directly into the sewer, with perhaps a pH adjustment. The only metal in this stream is iron, which is nonhazardous. If the stream goes to the treatment system, however (as it does at present), any sludge produced must be handled as hazardous waste, since it is mixed with hazardous sludges.

The plant envisions replacing the hexavalent chrome used for plating with trivalent chrome. There are many advantages to this. Most importantly from an environmental point of view, trivalent chrome is far less toxic than hexavalent. Also, a trivalent system requires only a dilute concentration of 1.5 oz/gal of chrome, while the hexavalent system requires 13 oz/gal of the much more toxic hexavalent chrome. Since concentrations are higher in hexavalent process baths, they tend to be higher in their waste streams as well. In addition, the higher concentration hexavalent baths are far more viscous than the trivalent baths, leading

to more dragout from the hexavalent baths. Trivalent systems have little air emissions, while in hexavalent systems, hydrogen bubbles are formed that entrain chromium compounds and lead to air emissions. In a hexavalent chrome setup, the waste treatment system must convert to hexavalent chrome to trivalent in order to precipitate it. This step is avoided in the trivalent setup. Finally, the plant management believes that the trivalent system will be far more efficient, produce fewer rejects and increase production.

## APPENDIX B

### WHERE TO GET HELP

### FURTHER INFORMATION ON POLLUTION PREVENTION

Additional information on source reduction, reuse and recycling approaches to pollution prevention is available in EPA reports listed in this section, and through state programs (listed below) that offer technical and/or financial assistance in the areas of pollution prevention and treatment.

In addition, waste exchanges have been established in some areas of the U.S. to put waste generators in contact with potential users of the waste. Four waste exchanges are listed below. Finally, EPA's regional offices are listed.

#### EPA REPORTS ON WASTE MINIMIZATION

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Corrosive and Heavy Metal Waste Minimization Audit at a Specialty Steel Manufacturing Complex." Executive Summary.\*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste for Parts Cleaning and from Electronic Capacitor Manufacturing Operation." Executive Summary.\*

U.S. Environmental Protection Agency. "Waste Minimization Audit Report: Case Studies of Minimization of Cyanide Wastes from Electroplating Operations." Executive Summary.\*

U.S. Environmental Protection Agency. Report to Congress: Waste Minimization, Vols. I and II. EPA/530-SW-86-033 and -034 (Washington, D.C.: U.S. EPA, 1986).\*\*

U.S. Environmental Protection Agency. Waste Minimization - Issues and Options, Vols. I-III EPA/530-SW-86-041 through -043. (Washington, D.C.: U.S. EPA, 1986).\*\*

\* Executive Summary available from EPA, WMDDRD, RREL, 26 West Martin Luther King Drive, Cincinnati, OH, 45268; full report available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Springfield, VA 22161.

\*\* Available from the National Technical Information Service as a five-volume set, NTIS No. PB-87-114-328.

#### WASTE REDUCTION TECHNICAL/ FINANCIAL ASSISTANCE PROGRAMS

The EPA's Office of Solid Waste and Emergency Response has set up a telephone call-in service to answer questions regarding RCRA and Superfund (CERCLA):

(800) 242-9346 (outside the District of Columbia)

(202) 382-3000 (in the District of Columbia)

The following states have programs that offer technical and/or financial assistance in the areas of waste minimization and treatment.

##### Alabama

Hazardous Material Management and Resources Recovery Program

University of Alabama

P.O. Box 6373

Tuscaloosa, AL 35487-6373

(205) 348-8401

##### Alaska

Alaska Health Project

Waste Reduction Assistance Program

431 West Seventh Avenue, Suite 101

Anchorage, AK 99501

(907) 276-2864

##### Arkansas

Arkansas Industrial Development Commission

One State Capitol Mall

Little Rock, AR 72201

(501) 371-1370

##### California

Alternative Technology Section

Toxic Substances Control Division

California State Department of Health Service

714/744 P Street

Sacramento, CA 94234-7320

(916) 324-1807

##### Connecticut

Connecticut Hazardous Waste Management Service

Suite 360

900 Asylum Avenue

Hartford, CT 06105

(203) 244-2007



Connecticut Department of Economic Development  
210 Washington Street  
Hartford, CT 06106  
(203) 566-7196

**Georgia**

Hazardous Waste Technical Assistance Program  
Georgia Institute of Technology  
Georgia Technical Research Institute  
Environmental Health and Safety Division  
O'Keefe Building, Room 027  
Atlanta, GA 30332  
(404) 894-3806

Environmental Protection Division  
Georgia Department of Natural Resources  
Floyd Towers East, Suite 1154  
205 Butler Street  
Atlanta, GA 30334  
(404) 656-2833

**Illinois**

Hazardous Waste Research and Information Center  
Illinois Department of Energy of Energy and Natural Resources  
1808 Woodfield Drive  
Savoy, IL 61874  
(217) 333-8940

Illinois Waste Elimination Research Center  
Pritzker Department of Environmental Engineering  
Alumni Building, Room 102  
Illinois Institute of Technology  
3200 South Federal Street  
Chicago, IL 60616  
(313) 567-3535

**Indiana**

Environmental Management and Education Program  
Young Graduate House, Room 120  
Purdue University  
West Lafayette, IN 47907  
(317) 494-5036

Indiana Department of Environmental Management  
Office of Technical Assistance  
P.O. Box 6015  
105 South Meridian Street  
Indianapolis, IN 46206-6015  
(317) 232-8172

**Iowa**

Center for Industrial Research and Service  
205 Engineering Annex  
Iowa State University  
Ames, IA 50011  
(515) 294-3420

Iowa Department of Natural Resources  
Air Quality and Solid Waste Protection Bureau  
Wallace State Office Building  
900 East Grand Avenue  
Des Moines, IA 50319-0034  
(515) 281-8690

**Kansas**

Bureau of Waste Management  
Department of Health and Environment  
Forbes Field, Building 730  
Topeka, KS 66620  
(913) 269-1607

**Kentucky**

Division of Waste Management  
Natural Resources and Environmental  
Protection Cabinet  
18 Reilly Road  
Frankfort, KY 40601  
(502) 564-6716

**Louisiana**

Department of Environmental Quality  
Office of Solid and Hazardous Waste  
P.O. Box 44307  
Baton Rouge, LA 70804  
(504) 342-1354

**Maryland**

Maryland Hazardous Waste Facilities Siting Board  
60 West Street, Suite 200 A  
Annapolis, MD 21401  
(301) 974-3432

Maryland Environmental Service  
2020 Industrial Drive  
Annapolis, MD 21401  
(301) 269-3291  
(800) 492-9188 (in Maryland)

**Massachusetts**

Office of Safe Waste Management  
Department of Environmental Management  
100 Cambridge Street, Room 1094  
Boston, MA 02202  
(617) 727-3260

Source Reduction Program  
Massachusetts Department of Environmental Quality Engineering  
1 Winter Street  
Boston, MA 02108  
(617) 292-5982

**Michigan**

Resource Recovery Section  
Department of Natural Resources  
P.O. Box 30028  
Lansing, MI 48909  
(517) 373-0540

**Minnesota**

Minnesota Pollution Control Agency  
Solid and Hazardous Waste Division  
520 Lafayette Road  
St. Paul, MN 55155  
(612) 296-6300

Minnesota Technical Assistance Program  
W-140 Boynton Health Service  
University of Minnesota  
Minneapolis, MN 55455  
(612) 625-9677

(800) 247-0015 (in Minnesota)  
Minnesota Waste Management Board  
123 Thorson Center  
7323 Fifty-Eighth Avenue North  
Crystal, MN 55428  
(612) 536-0816

**Missouri**

State Environmental Improvement and Energy  
Resources Agency  
P.O. Box 744  
Jefferson City, MO 65102  
(314) 751-4919

**New Jersey**

New Jersey Hazardous Waste Facilities Siting  
Commission  
Room 614  
28 West State Street  
Trenton, NJ 08608  
(609) 292-1459  
(609) 292-1026

Hazardous Waste Advisement Program  
Bureau of Regulation and Classification  
New Jersey Department of Environmental  
Protection  
401 East State Street  
Trenton, NJ 08625  
Risk Reduction Unit  
Office of Science and Research  
New Jersey Department of Environmental Protection  
401 East State Street  
Trenton, NJ 08625

**New York**

New York State Environmental Facilities  
Corporation  
50 Wolf Road  
Albany, NY 12205  
(518) 457-3273

**North Carolina**

Pollution Prevention Pays Program  
Department of Natural Resources and  
Community Development  
P.O. Box 27687  
512 North Salisbury Street  
Raleigh, NC 27611  
(919) 733-7015

Governor's Waste Management Board  
325 North Salisbury Street  
Raleigh, NC 27611  
(919) 733-9020

Technical Assistance Unit  
Solid and Hazardous Waste Management Branch  
North Carolina Department of Human Resources  
P.O. Box 2091  
306 North Wilmington Street  
Raleigh, NC 27602  
(919) 733-2178

**Ohio**

Division of Solid and Hazardous Waste Management  
Ohio Environmental Protection Agency  
P.O. Box 1049  
1800 WaterMark Drive  
Columbus, OH 43266-1049  
(614) 481-7200  
Ohio Technology Transfer Organization  
Suite 200  
65 East State Street  
Columbus, OH 43266-0330  
(614) 466-4286

**Oklahoma**

Industrial Waste Elimination Program  
Oklahoma State Department of Health  
P.O. Box 53551  
Oklahoma City, OK 73152  
(405) 271-7353

**Oregon**

Oregon Hazardous Waste Reduction Program  
Department of Environmental Quality  
811 Southwest Sixth Avenue  
Portland, OR 97204  
(503) 229-5913

**Pennsylvania**

Pennsylvania Technical Assistance Program  
501 F. Orvis Keller Building  
University Park, PA 16802  
(814) 865-0427

Center of Hazardous Material Research  
320 William Pitt Way  
Pittsburgh, PA 15238  
(412) 826-5320

Bureau of Waste Management  
Pennsylvania Department of  
Environmental Resources  
P.O. Box 2063  
Fulton Building  
3rd and Locust Streets  
Harrisburg, PA 17120  
(717) 787-6239

**Rhode Island**

Ocean State Cleanup and Recycling Program  
Rhode Island Department of Environmental Management  
9 Hayes Street  
Providence, RI 02908-5003  
(401) 277-3434  
(800) 253-2674 (in Rhode Island)

Center for Environmental Studies  
Brown University  
P.O. Box 1943  
135 Angell Street  
Providence, RI 02912  
(401) 863-3449

**Tennessee**

Center for Industrial Services  
102 Alumni Hall  
University of Tennessee  
Knoxville, TN 37996  
(615) 974-2456

**Virginia**

Office of Policy and Planning  
Virginia Department of Waste Management  
11th Floor, Monroe Building  
101 North 14th Street  
Richmond, VA 23219  
(804) 225-2667

**Washington**

Hazardous Waste Section  
Mail Stop PV-11  
Washington Department of Ecology  
Olympia, WA 98504-8711  
(206) 459-6322

**Wisconsin**

Bureau of Solid Waste Management  
Wisconsin Department of Natural Resources  
P.O. Box 7921  
101 South Webster Street  
Madison, WI 53707  
(608) 267-3763

**Wyoming**

Solid Waste Management Program  
Wyoming Department of Environmental Quality  
Herchler Building, 4th Floor, West Wing  
122 West 25th Street  
Cheyenne, WY 82002  
(307) 777-7752

**WASTE EXCHANGES**

Northeast Industrial Exchange  
90 Presidential Plaza, Syracuse, NY 13202  
(315) 422-6572

Southern Waste Information Exchange  
P.O. Box 6487, Tallahassee, FL 32313  
(904) 644-5516

California Waste Exchange  
Department of Health Services  
Toxic Substances Control Division  
Alternative Technology & Policy Development Section  
714 P Street  
Sacramento, CA 95814  
(916) 324-1807

**U.S. EPA REGIONAL OFFICES**

Region 1 (VT, NH, ME, MA, CT, RI)  
John F. Kennedy Federal Building  
Boston, MA 02203  
(617) 565-3715

Region 2 (NY, NJ)  
26 Federal Plaza  
New York, NY 10278  
(212) 264-2525

Region 3 (PA, DE, MD, WV, VA)  
841 Chestnut Street  
Philadelphia, PA 19107  
(215) 597-9800

Region 4 (KY, TN, NC, SC, GA, FL, AL, MS)  
345 Courtland Street, NE  
Atlanta, GA 30365  
(404) 347-4727

Region 5 (WI, MN, MI, IL, IN, OH)  
230 South Dearborn Street  
Chicago, IL 60604  
(312) 353-2000

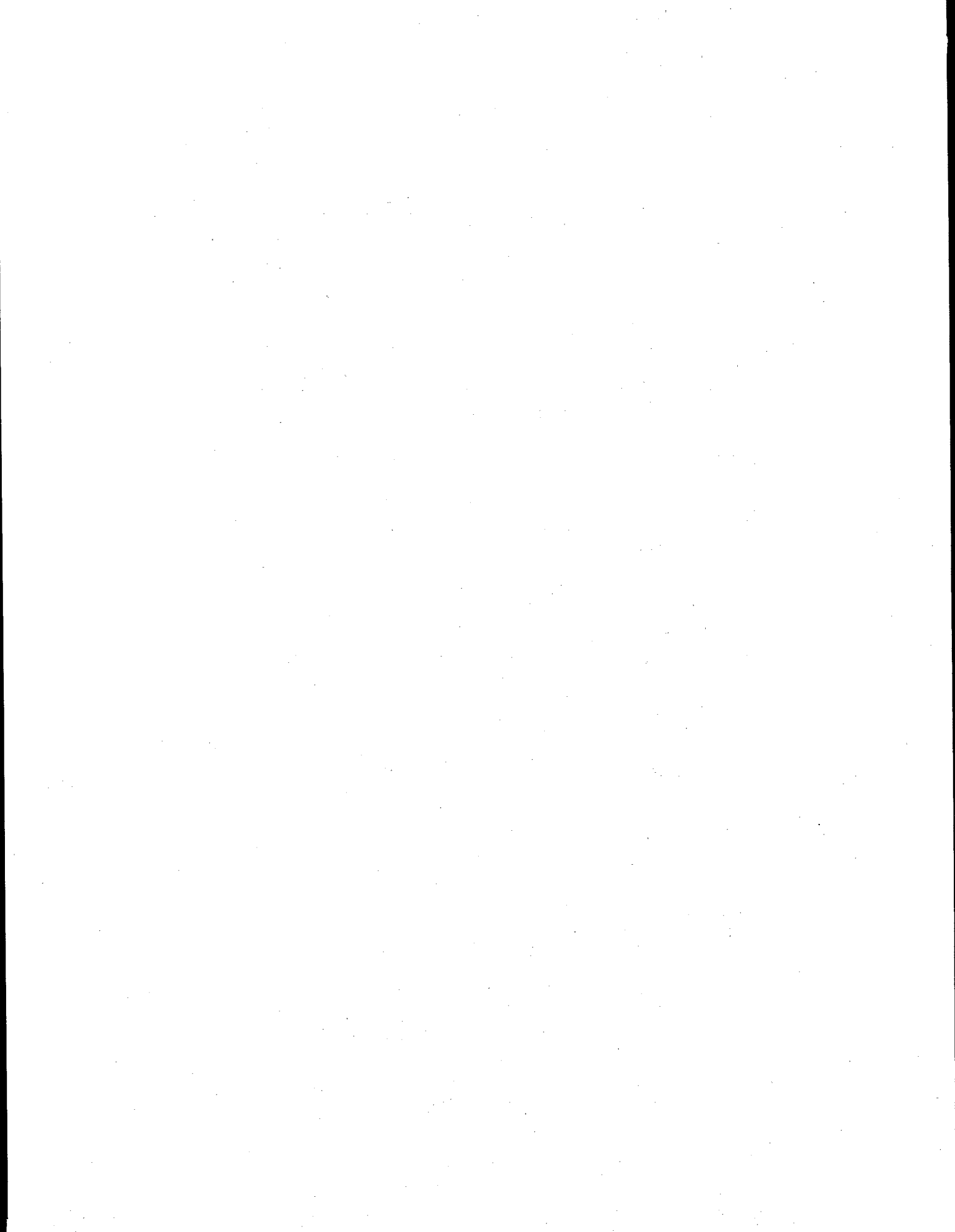
Region 6 (NM, OK, AR, LA, TX)  
1445 Ross Avenue  
Dallas, TX 75202  
(214) 655-6444

Region 7 (NE, KS, MO, IA)  
756 Minnesota Avenue  
Kansas City, KS 66101  
(913) 236-2800

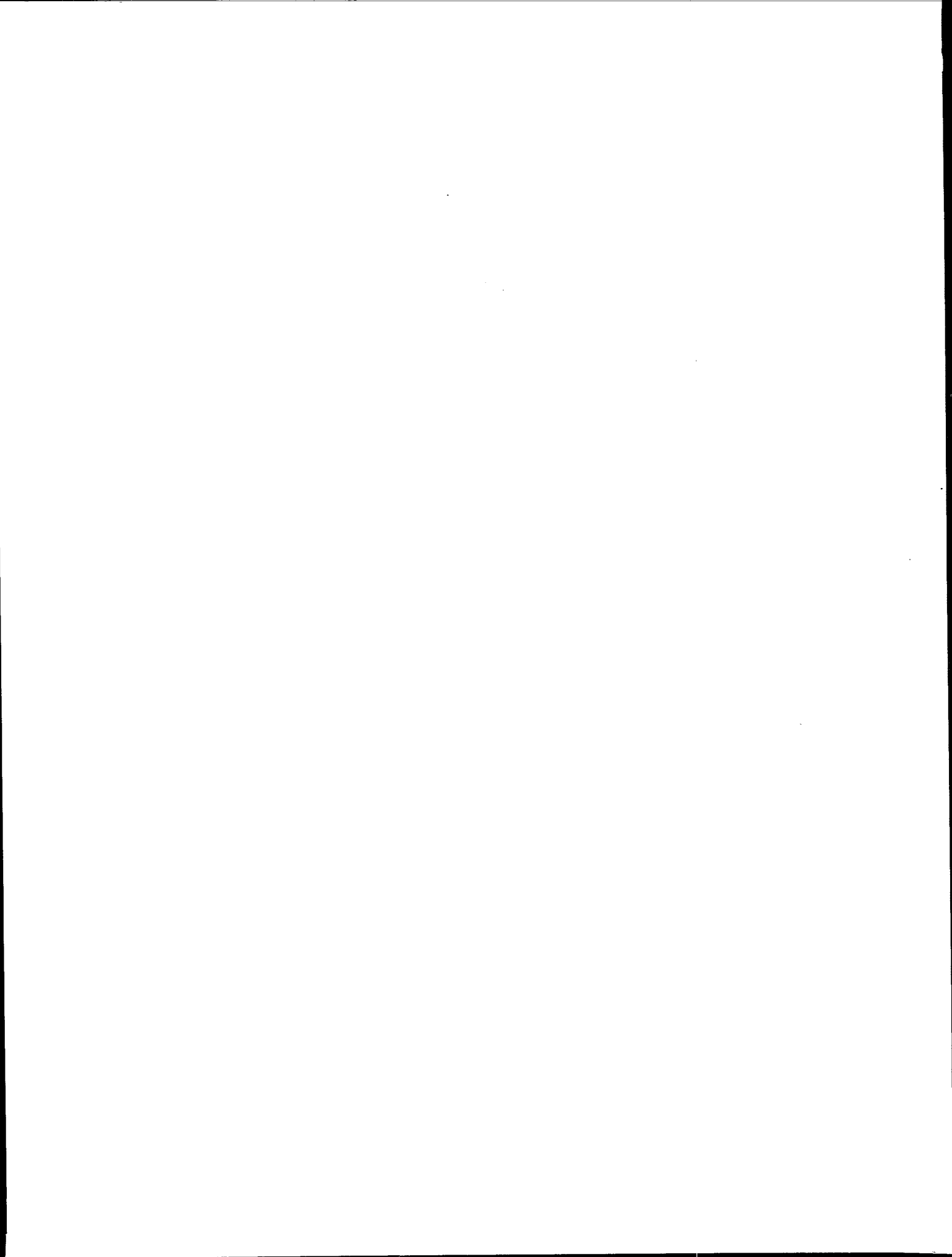
Region 8 (MT, ND, SD, WY, UT, CO)  
999 18th Street  
Denver, CO 80202-2405  
(303) 293-1603

Region 9 (CA, NV, AZ, HI)  
215 Fremont Street  
San Francisco, CA 94105  
(415) 974-8071

Region 10 (AK, WA, OR, ID)  
1200 Sixth Avenue  
Seattle, WA 98101  
(206) 442-5810







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Center for Environmental Research  
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