

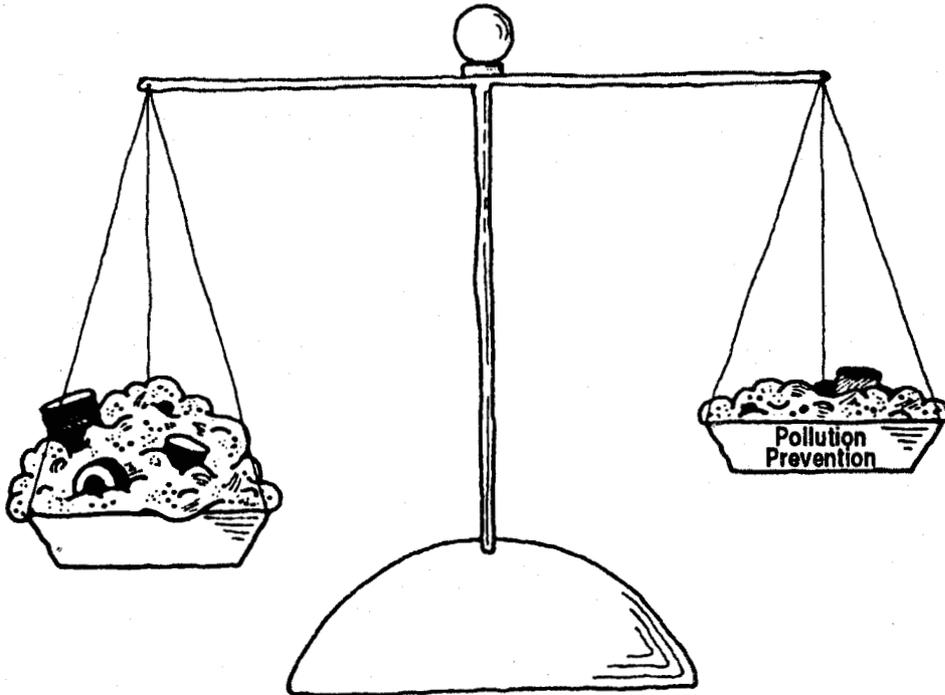


Illinois Environmental
Protection Agency

OFFICE OF POLLUTION PREVENTION

Metal Cleaning and Coating

June 1995







**Center for
Hazardous
Materials
Research**

STUDENT MANUAL

Metal Cleaning and Coating Pollution Prevention and Recycling

June 1995

Prepared for

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TABLE OF CONTENTS

	<u>PAGE</u>
1.0 INTRODUCTION	1-1
1.1 HISTORY AND EVOLUTION	1-1
1.1.1 Cleaning	1-1
1.1.2 Coating	1-1
1.2 TYPES OF FACILITIES IMPACTED	1-2
1.3 RAW MATERIALS	1-3
1.4 WASTE STREAMS	1-3
2.0 PROCESS INFORMATION	2-1
3.0 DISCUSSION OF PRODUCTION PROCESSES	3-1
3.1 CLEANING PROCESSES	3-1
3.1.1 Solvent Cleaning	3-1
3.1.2 Aqueous Cleaning	3-4
3.1.3 Semi-Aqueous Cleaning	3-5
3.1.4 Mechanical Surface Cleaning	3-5
3.2 COATING MATERIALS AND APPLICATION METHODS	3-5
3.2.1 Coating Components	3-5
3.2.2 Types of Coatings	3-6
3.2.3 Application Methods	3-6
3.2.4 Pollution Control	3-16
3.3 CURING	3-17
3.4 EQUIPMENT CLEANUP	3-17
4.0 POLLUTION PREVENTION OPPORTUNITIES	4-1
4.1 WASTE REDUCTION OPPORTUNITIES DURING METAL CLEANING	4-1
4.1.1 Waste Reduction During Solvent Cleaning	4-2
4.1.2 Waste Reduction During Aqueous and Semi-Aqueous Cleaning	4-23
4.1.3 Waste Reduction During Mechanical Surface Cleaning	4-24
4.2 WASTE REDUCTION OPPORTUNITIES DURING METAL COATING	4-25
4.2.1 Waste Reduction During Coating Application	4-25
4.2.2 Waste Reduction During Equipment Cleanup	4-27

TABLE OF CONTENTS (Cont.)

5.0	RECYCLING OPPORTUNITIES	5-1
5.1	RECYCLING OPPORTUNITIES DURING METAL CLEANING	5-1
5.1.1	Solvent Recycling	5-1
5.1.2	Aqueous and Semi-Aqueous Cleaning	5-4
5.2	RECYCLING OPPORTUNITIES DURING METAL COATING	5-4
5.2.1	Solvent Recovery from Air Emissions	5-4
5.2.2	Equipment Cleaning Wastes	5-4
6.0	OBSTACLES TO POLLUTION PREVENTION	6-1
6.1	REGULATORY OBSTACLES	6-1
6.2	OTHER OBSTACLES	6-1
APPENDIX A	CHEMICAL TOXICITY/REGULATORY STATUS CONSIDERATIONS FOR MATERIALS SUBSTITUTIONS	
APPENDIX B	HOW TO DEVELOP A "BEST-IN-CLASS" FACILITY LEVEL POLLUTION PREVENTION PROGRAM	
APPENDIX C	REFERENCES	

LIST OF TABLES AND FIGURES

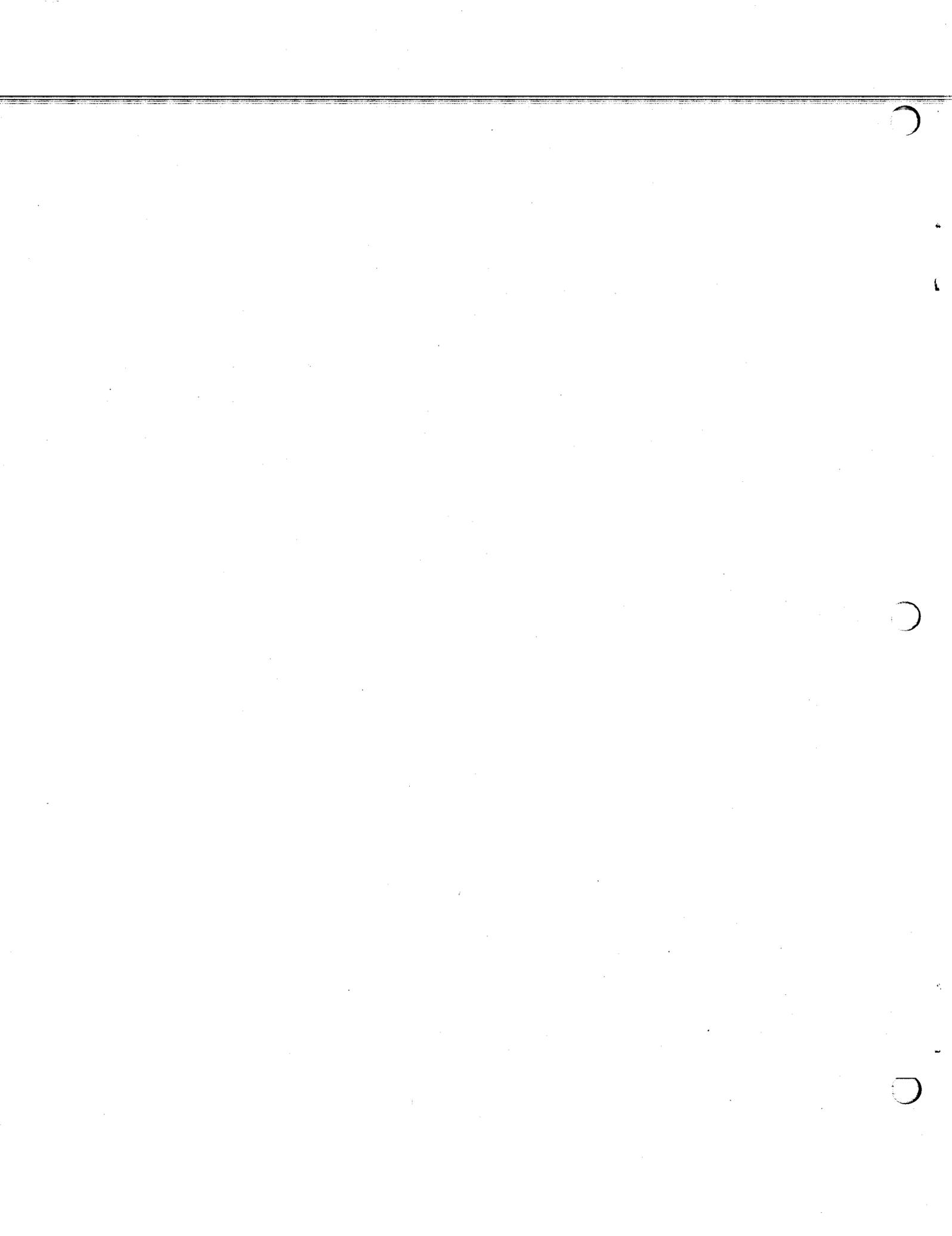
PAGE

TABLES

<u>Table</u>	<u>Title</u>	
1-1	Primary Types of Industries/No. of Facilities Involved in Metal Cleaning and Coating	1-2
3-1	Summary of Coating Application Processes	3-16
4-1	Pollution Prevention Practices for Metal Parts Cleaning Solvents	4-3
4-2	How to Select an Aqueous Cleaner	4-9
4-3	Suggested Solvent Alternatives	4-10
5-1	Solvent Air Emissions Recovery Systems	5-3
A-1	Metals and Inorganics	A-3
A-2	Regulated Toxic Metals -- RCRA	A-4
A-3	Regulated Toxic Metals -- Human Health	A-5
A-4	Regulated Toxic Metals -- Aquatic Organisms	A-6
A-5	Other Metals and Inorganics	A-7
A-6	Common Organic Solvents	A-9

FIGURES

<u>Figure</u>	<u>Title</u>	
2-1	Typical Coating Operation	2-1
3-1	Soak Cleaning Unit	3-2
3-2	Vapor Degreaser	3-3
3-3	Typical Aqueous Cleaning Flow Diagram	3-4
3-4	Spray Coating Systems	3-9
3-5	Dip Coating Line	3-10
3-6	Electrocoating System	3-11
3-7	Coil Coating Line	3-12
3-8	Powder Coating by Electrostatic Spray Gun	3-13
3-9	Powder Coating Recovery System	3-14
3-10	Powder Coating by Fluidized Bed	3-15



1.0 INTRODUCTION

1.1 HISTORY AND EVOLUTION

1.1.1 Cleaning

Traditionally, metal parts have been cleaned with organic solvents in either soak tanks or vapor degreasers. Although these methods are simple, efficient and cost-effective, many of the solvents are considered hazardous to human health and the environment. For instance, the production and use of chlorofluorocarbons and methyl chloroform, which are considered ozone-depleting chemicals under the 1990 Clean Air Act Amendments, are being phased out. Other solvents, such as methylene chloride, trichloroethylene, and tetrachloroethylene may still be used in vapor degreasing. However, they release volatile organic compounds, whose emissions are regulated as hazardous air pollutants. In addition, chlorinated solvent wastes must be handled as hazardous wastes. Finally, such solvents are expensive and subject to steep federal excise tax.

Faced with the phaseout of certain ozone-depleting chemicals, tightening air regulations, and the rising costs to use and dispose of solvents, industry has been forced to explore alternative cleaning materials and techniques, such as aqueous, semi-aqueous, and mechanical cleaning. Although many of these techniques have been available for years, driving forces to switch to these methods have not developed until recent years. Aqueous systems were developed over thirty-five years ago, and continue to be refined to meet a variety of customer needs. In many cases, vendors of aqueous systems offer a variety of customer services, including testing and analysis, demonstrations, technical and feasibility studies, and reports detailing results.

1.1.2 Coating

Coatings have also been historically solvent-based. Solvent-based coatings have desirable characteristics such as durability, fast drying time, low corrosivity to substrate, and high gloss finish. These solvent-based coatings have frequently been applied by spraying. However, industrial coating materials must now be applied to manufactured products in compliance with a variety of regulations controlling air and water quality, hazardous material disposal, and workplace safety. These regulations have forced industry to look for alternative coating materials and application methods to improve efficiency and reduce air emissions and other wastes, while still meeting product specifications.

As a result, a variety of coating materials, such as water-based, powder, radiation curable, and two-component coatings have been developed and refined for use in many current coating applications. Coating manufacturers continue to improve coating characteristics and explore new applications. For example, powder manufacturers continually work to develop powders that can form thinner films, lower temperature cures, and exhibit superior weathering capabilities. Similarly, more efficient application equipment has been developed to work with solvent-based coatings and to accommodate alternative coating materials.

1.2 TYPES OF FACILITIES IMPACTED

Metal cleaning and coating are integral process operations for a range of industries involved with the manufacture and/or maintenance of metal parts and equipment. Table 1-1 provides statistics compiled by American Business Information, Inc. (Omaha, Nebraska) for the primary industries in SIC codes typically associated with cleaning and coating related activities.

TABLE 1-1 PRIMARY TYPES OF INDUSTRIES/NO. OF FACILITIES INVOLVED IN METAL CLEANING AND COATING			
SIC	Description	Illinois Facilities	U.S. Facilities
2514	Metal household furniture	25	424
3411	Metal cans	52	371
3412	Metal shipping barrels, drums, kegs/pails	43	802
3442	Metal doors, sash, frames, molding, and trim	108	2502
3444	Sheet metal work	238	6035
3469	Metal stampings, nec	355	5073
3479	Coating, engraving, and allied services	385	9324
3499	Fabricated metal products, nec	206	4219
3523	Farm machinery and equipment	105	2775
3531	Construction machinery and equipment	85	2005
3564	Industrial and commercial fans and blowers	69	979
3585	Air conditioning and heating equipment	58	1359
3631	Household cooking equipment	16	162
3632	Household refrigerators and freezers	4	55
3633	Household laundry equipment	3	32
3635	Household vacuum cleaners	4	79
3639	Household appliances, nec	16	260
3711	Motor vehicles and passenger car bodies	39	1341
3713	Truck and bus bodies	19	736
3714	Motor vehicle parts and accessories	427	6702
3743	Railroad equipment	46	378
7532	Top and body repair and paint shops	3322	83236
TOTAL		5625	128829

Source: American Business Information, Inc., May 1995

1.3 RAW MATERIALS

Raw materials for cleaning may include solvents, aqueous and semi-aqueous cleaning solutions, water, abrasive materials, and rags.

Raw materials for coating (and cleanup operations) may include coatings, solvents, water, rags, and various types of application equipment.

1.4 WASTE STREAMS

Waste streams from cleaning operations may include spent solvents, dirty aqueous and semi-aqueous cleaning solutions, spent abrasives, waste rinsewaters, sludge with metals from wastewater treatment, dirty rags, empty containers, and volatile organic compound (VOC) emissions.

Waste streams from coating operations may include coating scraps; spilled or leftover coatings; empty containers; scrubber water, coating sludge, and filters from air pollution control; and VOC emissions.

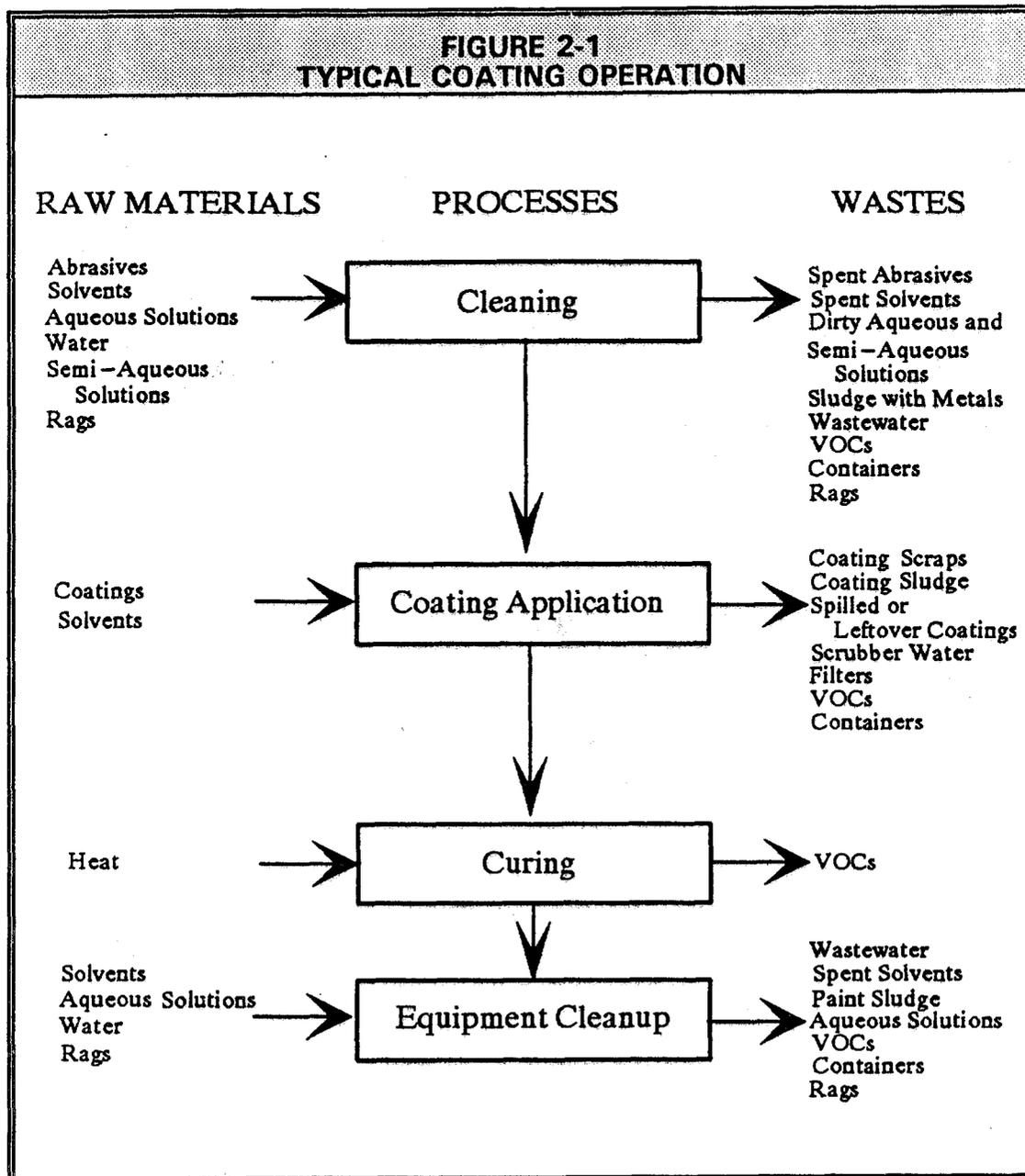
Curing may produce VOC emissions.

Equipment cleaning is another major source of waste generation from coating application. Generally, all coating application equipment must be cleaned after each use to prevent dry coating residue and avoid contaminating batch processes. Wastes generated include spent organic solvents, aqueous cleaners, wastewaters, coating sludge, dirty rags, and VOC emissions.

2.0 PROCESS INFORMATION

As shown in Figure 2.1, a typical sequence of a metal coating operation involves:

- Cleaning or pretreatment
- Coating application
- Curing
- Equipment cleanup



3.0 DISCUSSION OF PRODUCTION PROCESSES

The following sections describe in more detail each of the components outlined in Section 2.0.

3.1 CLEANING PROCESSES

Metal cleaning is an essential step in the surface preparation of a part prior to coating. Cleaning processes are distinguished by (1) the cleaning medium and (2) the cleaning method or equipment. Cleaning media used by industry includes solvents, aqueous cleaners, semi-aqueous cleaners, abrasive materials, and water. Equipment required for these cleaners range from rags for wipe cleaning to ultrasonic vibration. The following provides a summary of cleaning medium and associated cleaning equipment.

3.1.1 Solvent Cleaning

Solvents, such as trichloroethylene, 1,1,1-trichloroethane, methylene chloride, perchloroethylene, and trichlorotrifluorocarbon (CFC-113) are the most commonly used cleaners. Solvents are often used to remove oils, cutting fluids, and buffing compounds from metal parts. The primary users include metal furniture manufacturers, fabricated product manufacturers, electric equipment manufacturers, automobile repair shops, and the transportation industry. Solvent cleaning is accomplished via a variety of methods, including:

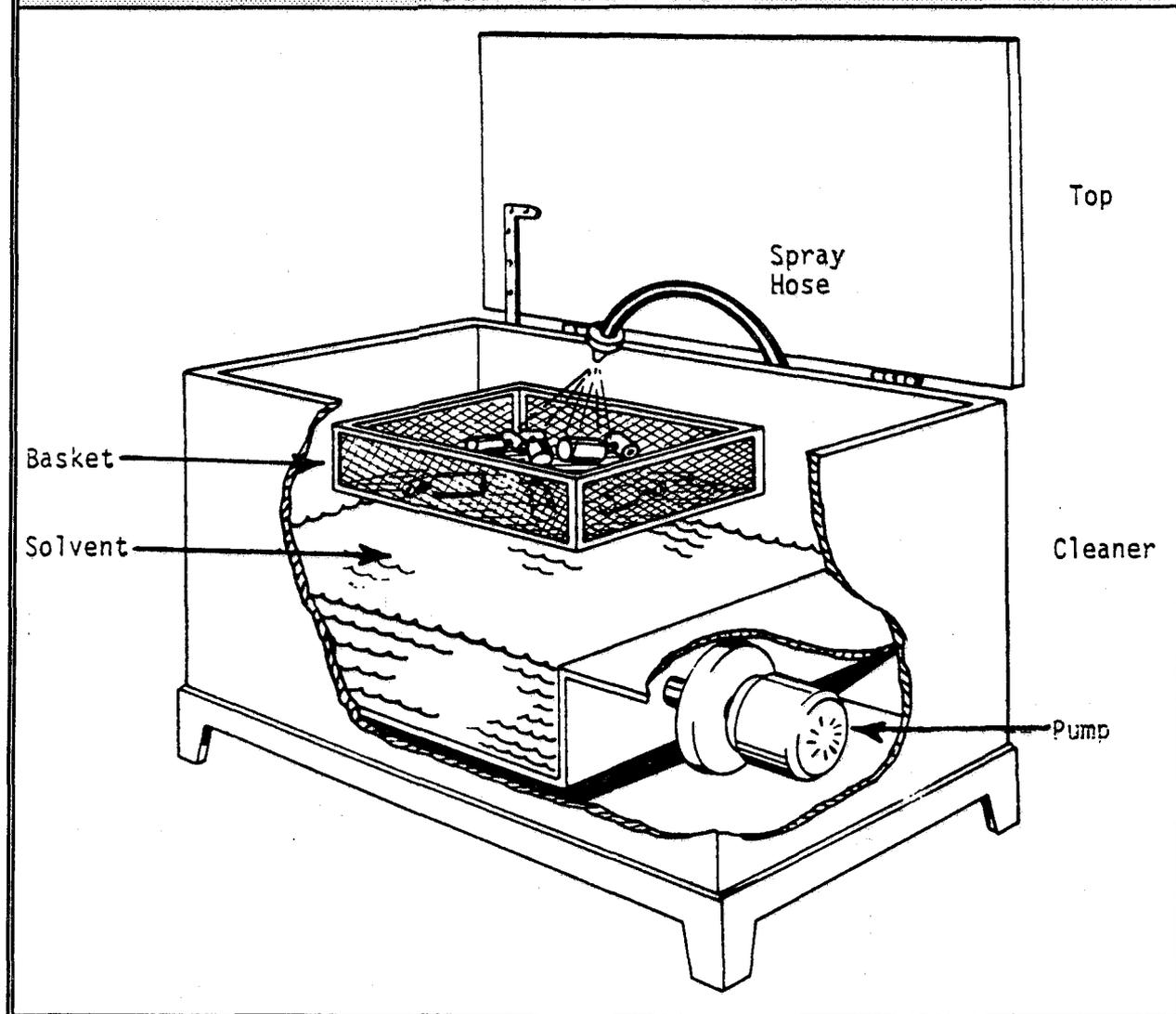
Wipe Cleaning

Wipe cleaning consists of soaking a clean rag with solvent and then wiping the part clean. It is usually associated with maintenance operations or processes that fabricate parts on a single item basis. Solvent use tends to be high because the only way to assure cleanliness is use a liberal amount of solvent. Wastes from wipe cleaning include dirty rags, air emissions, and spilled solvent.

Soak Cleaning

Soak cleaning consists of soaking parts in a tank of cold solvent. Small parts are usually handled in a barrel or wire-mesh basket while larger parts are placed on racks. Figure 3-1 shows a soak cleaning unit. When a higher degree of cleaning is required, the solvent may be heated slightly. For parts that have many crevices or hidden surfaces, an ultrasonic unit is sometimes added to the tank to provide a vigorous cleaning action. Wastes from soak cleaning include dirty solvent, waste rinsewater, and air emissions.

**FIGURE 3-1
SOAK CLEANING UNIT**



Source: U.S. EPA, *Control of Volatile Organic Emissions from Solvent Metal Cleaning*

Diphase Cleaning

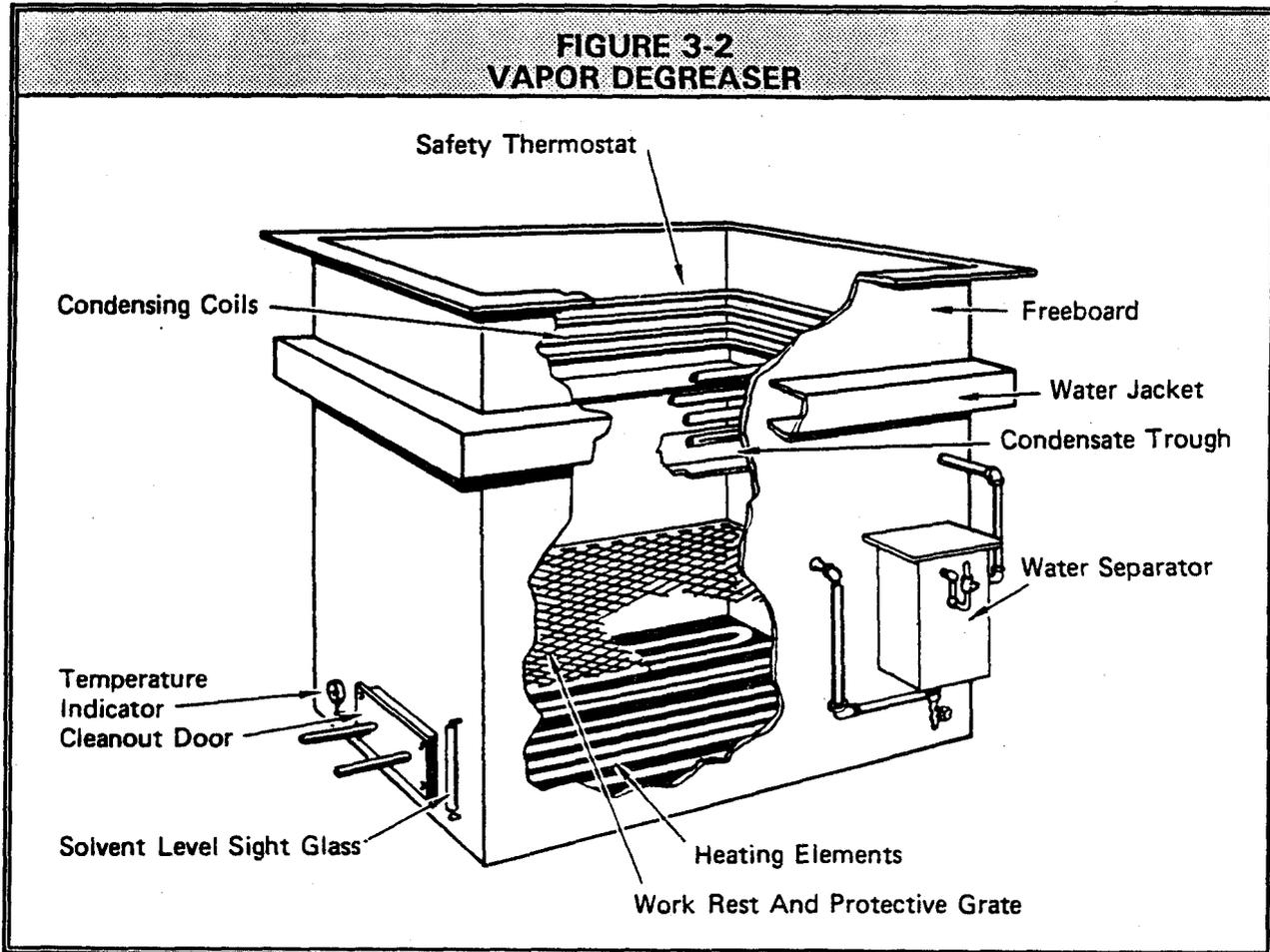
Diphase cleaning combines into one operation a water rinse both before and after the solvent cleaning step. Because halogenated solvents and water are relatively insoluble, they separate into two layers when placed together in a tank. The water, being less dense than the solvent, floats on top. Dirty parts are submerged first through the water and then the solvent. As the parts are removed, they are rinsed again by the same water. Wastes from diphase cleaning include dirty solvent, waste rinsewater, and air emissions.

Steam Gun Stripping

With steam gun stripping, a mixture of solvents passes through a steam gun onto the dirty parts. The solvent soaked parts are then steamed with pure steam. This process is usually used for the removal of coating from metal surfaces. Steam gun stripping wastes include dirty solvent, air emissions, dirty rinsewater, and sludge.

Vapor Degreasing

Vapor degreasing uses a tank of halogenated solvent heated to its boiling point. Dirty parts are placed in the hot solvent vapor of the degreaser. When solvent vapors condense on the parts, the contamination is dissolved and then rinsed away. To increase cleaning efficiency, parts may be immersed into the solvent bath or a solvent spray unit may be used. The potential for air emissions is greater with vapor degreasing operations than with "cold" solvent cleaning methods. A vapor degreasing unit is shown in Figure 3-2.



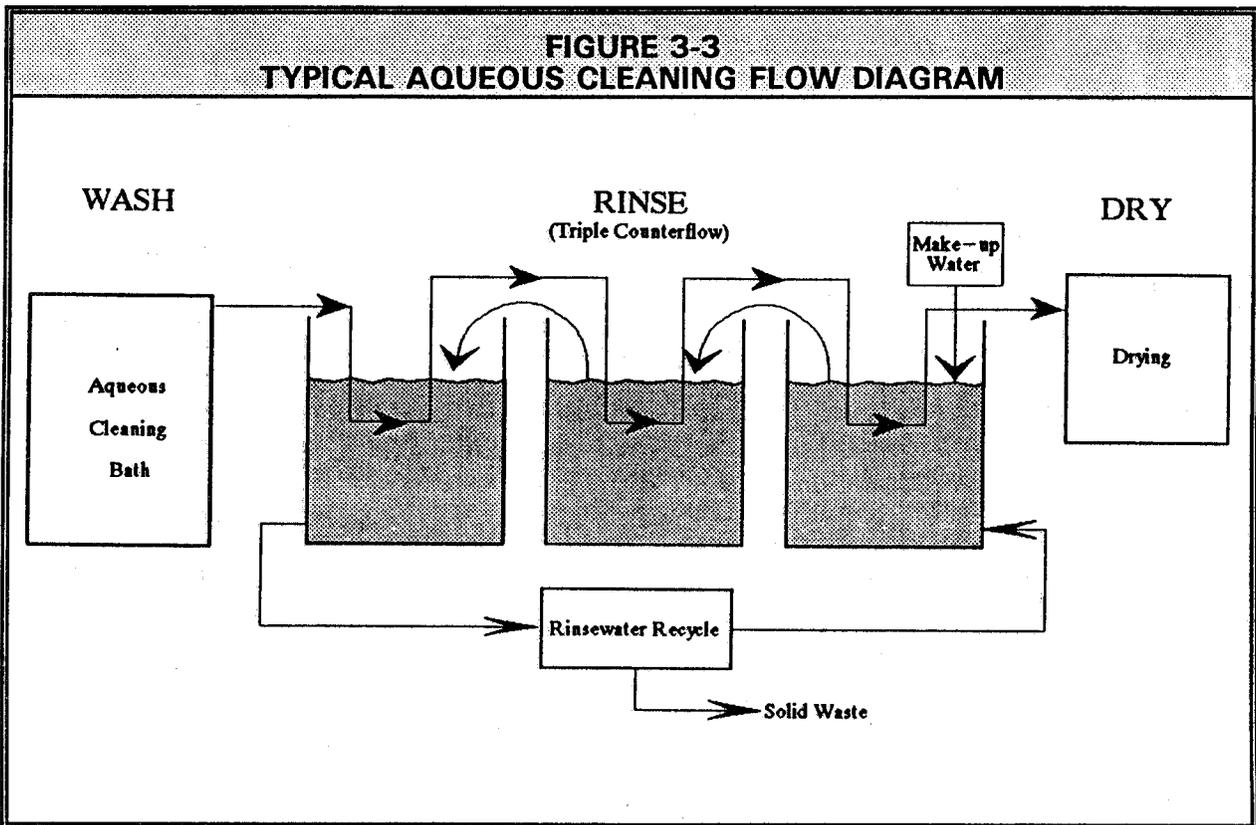
Source: U.S. EPA, *Control of Volatile Organic Emissions from Solvent Metal Cleaning*

3.1.2 Aqueous Cleaning

Aqueous cleaning systems use hot water and detergent in a three-step process -- wash, rinse, and dry. Alkaline aqueous cleaning chemistries consist of builders (alkaline salts), surfactants (emulsifiers and wetting agents), and organic and inorganic additives such as pH buffers, deflocculants and antifoaming agents. Acidic cleaning solutions contain a combination of mineral acids (nitric, sulfuric, and hydrochloric), organic acids (sulfamic, acetic, oxalic or cresylic), detergents, chelating agents, and occasionally small amounts of solvents.

In the process, parts to be cleaned are placed in a bath of alkaline or acidic cleaning solution. The bath may be agitated by moving the parts in the bath, pumping the solution around the bath, bubbling air through the bath, or vibrating the bath with an ultrasonic unit. The cleaning solution combined with the bath agitation dissolves contaminants such as oil and grease. Following cleaning, parts are rinsed to remove residual contaminants and surfactants, using a rinse tank or series of rinse tanks filled with high-purity water heated to between 110 and 170°F. In closed-loop systems, rinsewater is filtered and recycled to eliminate wastewater discharge. Cleaning solutions can also be reclaimed and recycled. After rinsing, parts are dried with forced-air dryers or ovens. Figure 3-3 shows a typical flow diagram for an aqueous cleaning system.

Wastes associated with aqueous cleaning include waste alkaline or acid solution, and waste rinsewater.



3.1.3 Semi-Aqueous Cleaning

Semi-aqueous cleaning systems use emulsified or concentrated hydrocarbon/surfactant in a three-step process similar to aqueous cleaning systems. Common semi-aqueous cleaners include: aliphatic hydrocarbons, esters, terpenes, alcohols, and n-methyl pyrrolidone. Additional information regarding these solvents is provided in Section 4.1.1.2. In semi-aqueous cleaning systems, the solvent is separated from rinsewater, allowing closed-loop recycling of water and solvent.

Wastes associated with semi-aqueous cleaning include waste cleaning solution and waste rinsewater.

3.1.4 Mechanical Surface Cleaning

Mechanical surface cleaning uses abrasive materials such as plastic, ceramic, carbon dioxide, or harder media such as aluminum oxide to remove oxidation layers, old plating, and coating and burrs from workpieces, and to create a smooth surface. A number of mechanical surface cleaning methods are available including blasting, tumbling, and vibratory finishing. *Blasting* involves propelling abrasive media against a surface to abrade away oxides and scale. Media is propelled by a stream of pressurized air or water, or by other mechanical means. In a *tumbling* process, small parts and abrasive media are loaded into a barrel or drum. When the drum is rotated, the parts and the media rub together and abrade away oxides and scale. With *vibratory finishing*, parts are loaded into a media-filled drum or tub that vibrates and abrasively cleans the parts.

Mechanical surface cleaning methods generate less waste than other techniques, with the primary waste being spent abrasive material.

3.2 COATING MATERIALS AND APPLICATION METHODS

The application of coatings to metal surfaces serves both a decorative and a protective purpose. A variety of coating materials and application methods are in use today. The following provides a summary of coating materials and application methods.

3.2.1 Coating Components

Coatings are comprised of four main components: pigment, binder, solvent, and additives. *Pigments* are tiny particles of organic or inorganic material that provide color and impart glossiness, opacity, and durability to the finish. The pigment type used in a coating formulation affects the toxicity of the coating waste. For this reason, many pigments containing heavy metal compounds are being discontinued. *Binders* provide the coating with adhesiveness and film continuity and are the primary component remaining after the coating is cured. Binders in coatings can be either natural or artificial polymeric resins. When cured, most resins used as binders are nontoxic and insoluble in water. Coatings are sometimes classified by the binder type, such as: alkyds, epoxies, polyesters, polyurethanes, and vinyls. *Solvents* are liquids added to coatings to disperse or dissolve the binder component and to modify the viscosity of the coating. Water and a wide range of organic chemicals are used as solvents in coatings. Generally, solvents are classified as hazardous due to toxicity

and/or ignitability characteristics. *Additives*, such as talc, clay, and silicates, are used to improve coating performance and coverage, enhance durability, and reduce material costs.

3.2.2 Types of Coatings

Coatings can be classified in a variety of ways. From the standpoint of pollution prevention and recycling, classification by the primary type of solvent contained in the coating is useful and the method used in this discussion. Based on this system, coatings can be classified as organic solvent-based, water-based, or formulations without water or solvent.

Organic Solvent-Based Coatings

Many "conventional" coatings are organic solvent-based and contain 60 to 80 percent volatile organic compounds (VOCs). Many of these VOCs are listed as hazardous air pollutants (HAPs) or toxic air pollutants. As a result, high-solids coatings have been developed that have a solids content of 50 to 70 percent. The higher solids content produces a coating that contains less solvent, but requires modifications to spraying equipment due to the greater viscosity of the coating.

Water-Based Coatings

In water-based coatings, water, usually in conjunction with an organic solvent, acts as the carrying medium. These types of coatings include aqueous emulsions (latex), colloidal dispersions, and water-reducible coatings.

The use of water-based coatings generally decreases VOC emissions, eliminates organic solvents for thinning, and reduces the use of organic solvents during cleanup.

Formulations Without Water or Solvents

These formulations include powder coatings, radiation-curable coatings, and two-component reactive liquid coatings:

Powder coatings are applied dry using electrostatic spray, fluidized bed, and flame spray application techniques and entirely eliminate the use of a solvent. After application, the adhered powder is melted with heat to provide a continuous film. Powder coatings eliminate nearly all VOCs and generate little overspray waste.

Radiation-curable coatings contain liquid reactive monomers that polymerize in the presence of ultraviolet, electron-beam, or infrared radiation. These formulations contain no solvent.

Two-component reactive liquid coatings consist of two separately packaged reactive resin formulations, neither of which contain a solvent. In contact with each other, the resins react on the surface of the metal part to produce a coating.

3.2.3 Application Methods

With numerous alternatives available, the selection of an application method depends on the type of coating, and the size and shape of the surface. A number of coating methods are described below.

Spray Coating

Spraying is the predominant method of applying coatings to metal parts and can be done either manually or automatically. In most industrial operations, spraying is performed in spray booths. Spray booths are semi-enclosed chambers of varying dimensions that confine, collect, and control pollutants generated during spraying operations. Pollutants from spraying include particulate matter, in the form of coating overspray, and VOCs. To control particulates, coating overspray is drawn by exhaust fans through either dry filters or water prior to discharge to the atmosphere. The control of VOCs from these operations is a much more difficult and expensive task. Due to the large volume of air needed to properly ventilate the spray chambers and drying ovens, add-on devices for VOC control are often cost prohibitive. Potential control methods include carbon adsorption and incineration.

Four major spray applications methods are in use today: (1) compressed-air atomization -- conventional air spray and high-volume, low pressure atomization (HVLP), (2) airless atomization, (3) air-assisted airless atomization, and (4) electrostatic atomization. Each of these methods is discussed below.

Compressed-air Atomization

The oldest and most widely used method, conventional air spray came into prominence during the 1920s. In this system, streams of liquid coating and compressed air mix either inside or outside of the spray gun and cause the mixture to atomize. Although conventional air spray equipment provides the operator with great versatility and control, the low level of transfer efficiency inherent with this equipment causes a large amount of overspray. A typical air spray gun is shown in Figure 3-4.

High-volume, low pressure (HVLP) spray guns have been developed that operate with a high volume of air delivered at 10 pounds per square inch (psi) or less to atomize the coating. These guns offer reduced overspray and increased transfer efficiency. However, the atomization provided may not be sufficient for fine finishes, and high production rates may not be possible.

Airless Atomization

As the name implies, airless spraying does not directly use compressed air to atomize the coating material. Rather, hydraulic pressure atomizes the coating by pumping it at high pressure through a small-orifice spray nozzle tip located at the front of the airless gun. As the coating is released at these high pressures, it separates into small droplets resulting in a finely atomized spray. Among the advantages of airless atomization are high rates of coating flow and relatively high transfer efficiency. Disadvantages include relatively poor atomization, expensive nozzles, and increased operator training required. A typical airless atomization spray system is shown in Figure 3-4.

Air-assisted Airless Atomization

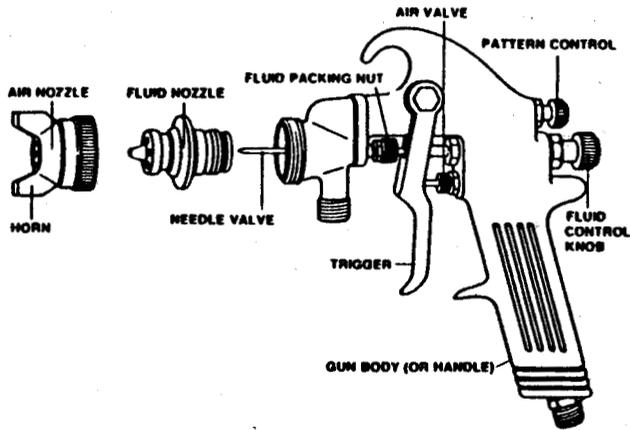
With air-assisted airless spray guns, coatings are first partially atomized with a special fluid nozzle tip similar to a standard airless tip. Atomization is then completed with small amounts of compressed air from the face and/or horns of the air nozzle. The result is a finely atomized spray pattern closely resembling that of a compressed air

system. These systems provided relatively good atomization and high coating transfer efficiency, but have higher capital costs and require increased operator training. Figure 3-4 includes a typical air-assisted airless system.

Electrostatic Atomization

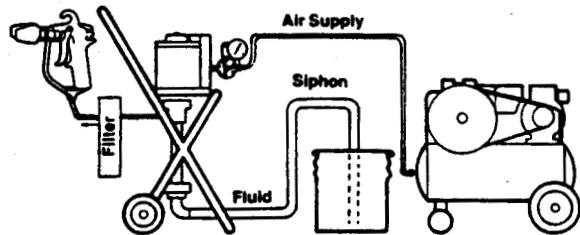
With an electrostatic spray gun, coating is first atomized using either the compressed-air, airless, or air-assisted airless methods. The atomized coating droplets are charged at the tip of the gun by a charging electrode. Because the part to be coated is electrically neutral, the charged coating droplets are attracted to the part. Advantages of electrostatic spray guns include high transfer efficiency, good edge cover, and uniform film thickness. Drawbacks include higher equipment and maintenance costs, difficulty in coating some corners and recesses, and safety and fire hazards. An electrostatic atomization spray system is shown in Figure 3-4.

FIGURE 3-4 SPRAY COATING SYSTEMS

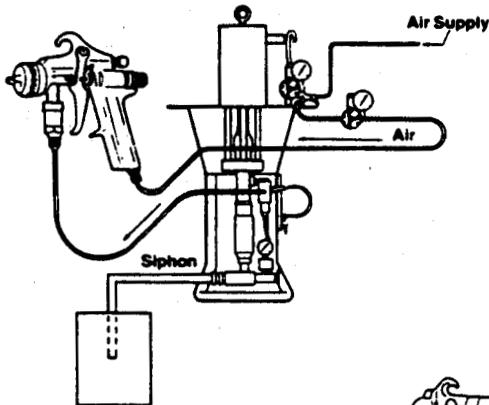


Typical air spray gun.

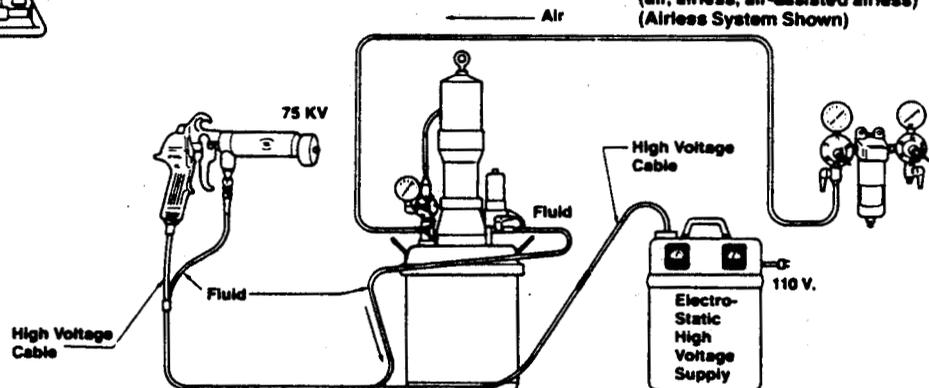
AIRLESS (Hydraulic atomization)



AIR ASSISTED AIRLESS ATOMIZATION



ELECTROSTATIC ATTRACTION
(air, airless, air-assisted airless)
(Airless System Shown)



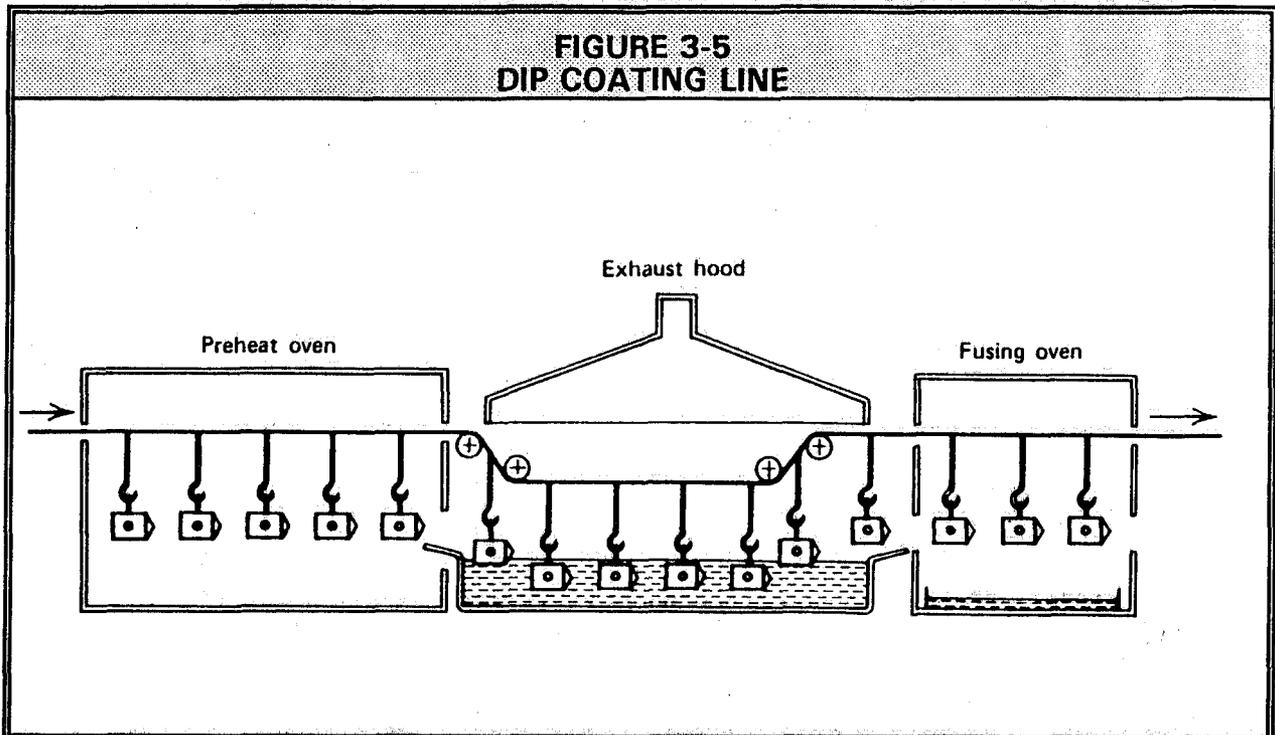
Source: *Metal Finishing 1994 Organic Finishing Guidebook and Directory*

Dip Coating

Dip application of a coating involves exactly what the name implies -- immersing a part in a tank of coating material, draining off the excess after withdrawal, and curing via force drying or baking. Film thickness is controlled by the viscosity of the coating and rate of withdrawal from the tank. Dip tanks can be shaped and sized to accommodate a broad range of objects. Dip coating is a fast and efficient finishing method used by a variety of industries for both primer and one-coat finishes.

Dip coating provides transfer efficiencies as high as 95 to 100 percent, has minimal manpower and equipment requirements, and is easily automated. However, improperly racked parts can bucket coating, leading to waste and potential blistering. In addition, a change from one formulation to another requires either extensive cleaning and recharging of a single tank or the availability of multiple dip tanks.

A dip coating line is shown in Figure 3-5.



Source: *Encyclopedia of Chemical Technology*

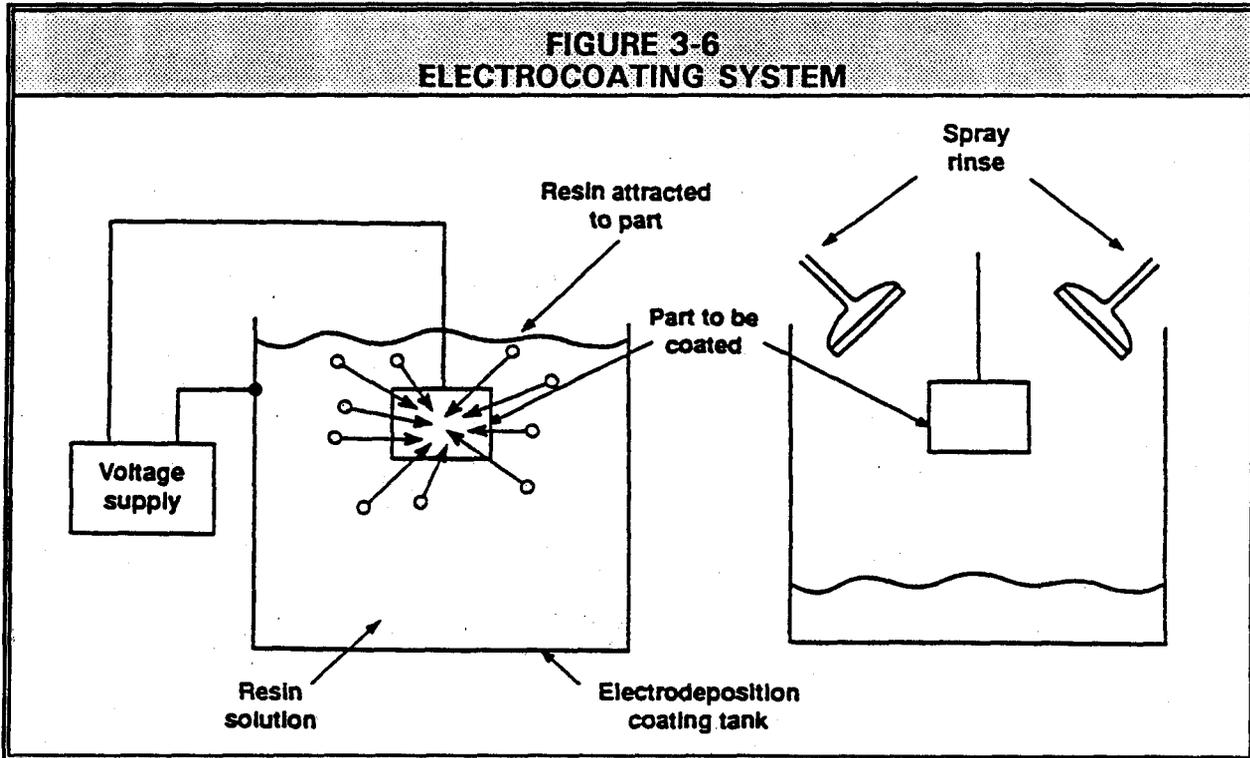
Electrocoating

Electrocoating, or electrodeposition, is a dipping method where negatively charged coating particles are electrically plated out of water suspension and deposited as a film on a conductive object. This operation usually involves deposition of coatings on the anode from a slightly alkaline coating bath. However, more recently developed materials deposit on the cathode from a slightly acidic bath.

Electrocoating provides a 95 to 100 percent transfer efficiency. Other advantages of electrocoating include decreased solvent emissions, improved coverage of inaccessible

areas, and reduced labor requirements. Drawbacks include higher capital equipment and material costs, and the need for more highly trained operators.

Figure 3-6 shows an electrocoating system.



Source: *Spray Painting: Improvements and Alternatives*

Flow Coating

Flow coating overcomes many of the limitations of conventional dip coating. This method involves pouring coating over the part to be coated as it is held over a tank. The excess coating is collected and recirculated.

While flow coating provides high transfer efficiency and requires little labor and maintenance, it yields only a poor to fair appearance.

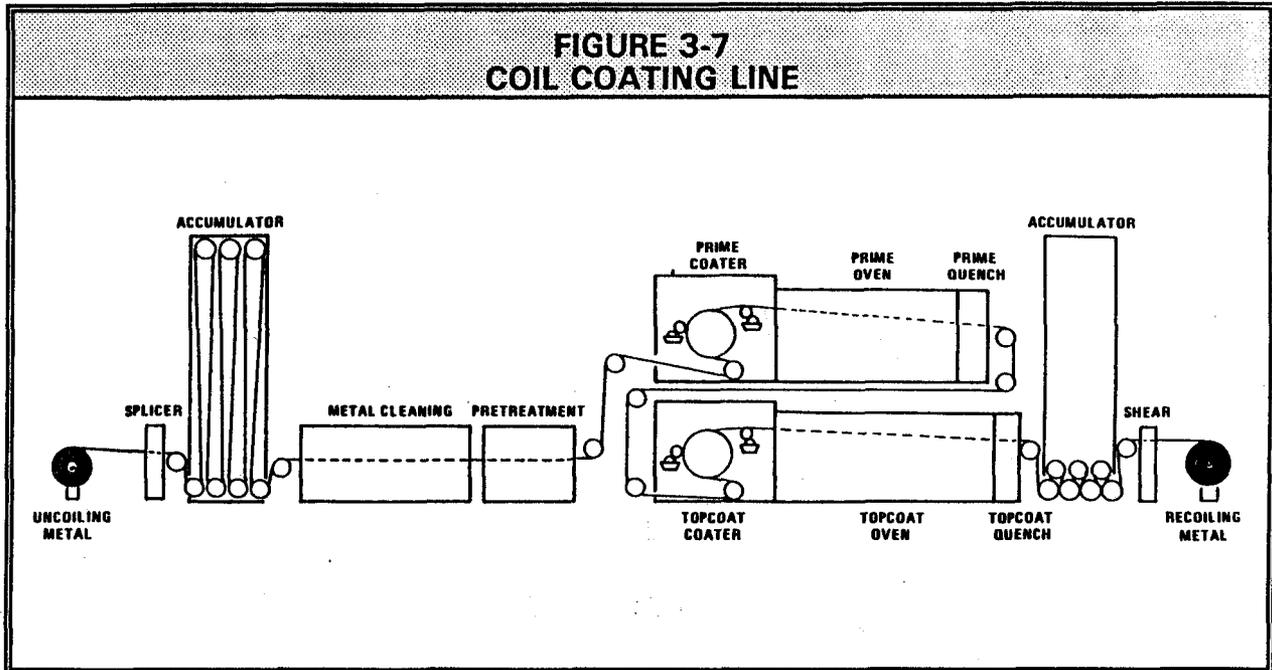
Curtain Coating

Curtain coaters are modified flow coaters used mainly on high-speed, conveyORIZED production lines for coating flat parts. In these units, the coating falls in an unbroken stream, or "curtain," over parts that pass underneath it. Excess coating is collected for reuse.

Curtain coating provides high transfer efficiency and makes uniform coating thickness possible. However, this technique is suitable only for flat parts and is highly dependent on the coating viscosity.

Roller Coating

In roller coating, coatings are applied to a roller and transferred directly to a part by contact. Roller coating is an important technique for finishing flat sheets. When applied on a continuous strip, this method is called *coil coating*. A coil coating line is shown in Figure 3-7. While roller coating offers high transfer efficiencies and high production rates, it is limited to flat parts without hard-to-reach areas.



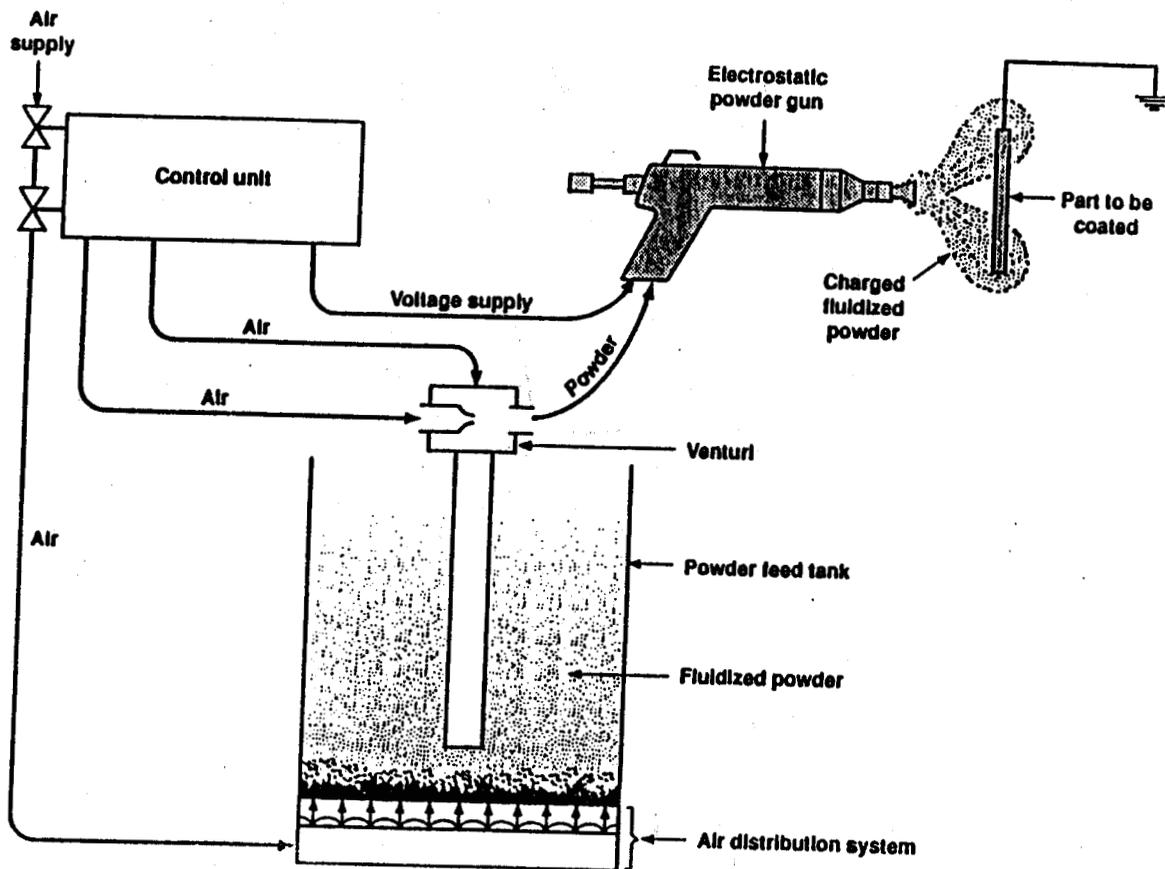
Source: U.S. EPA, *Control of Volatile Organic Emissions From Existing Stationary Sources - Volume II*

Powder Coating

In powder coating, a layer of dry powdered resin is applied on the surface to be covered and then melted. The powder is applied using either an electrostatic spray gun or an electrostatic fluidized bed.

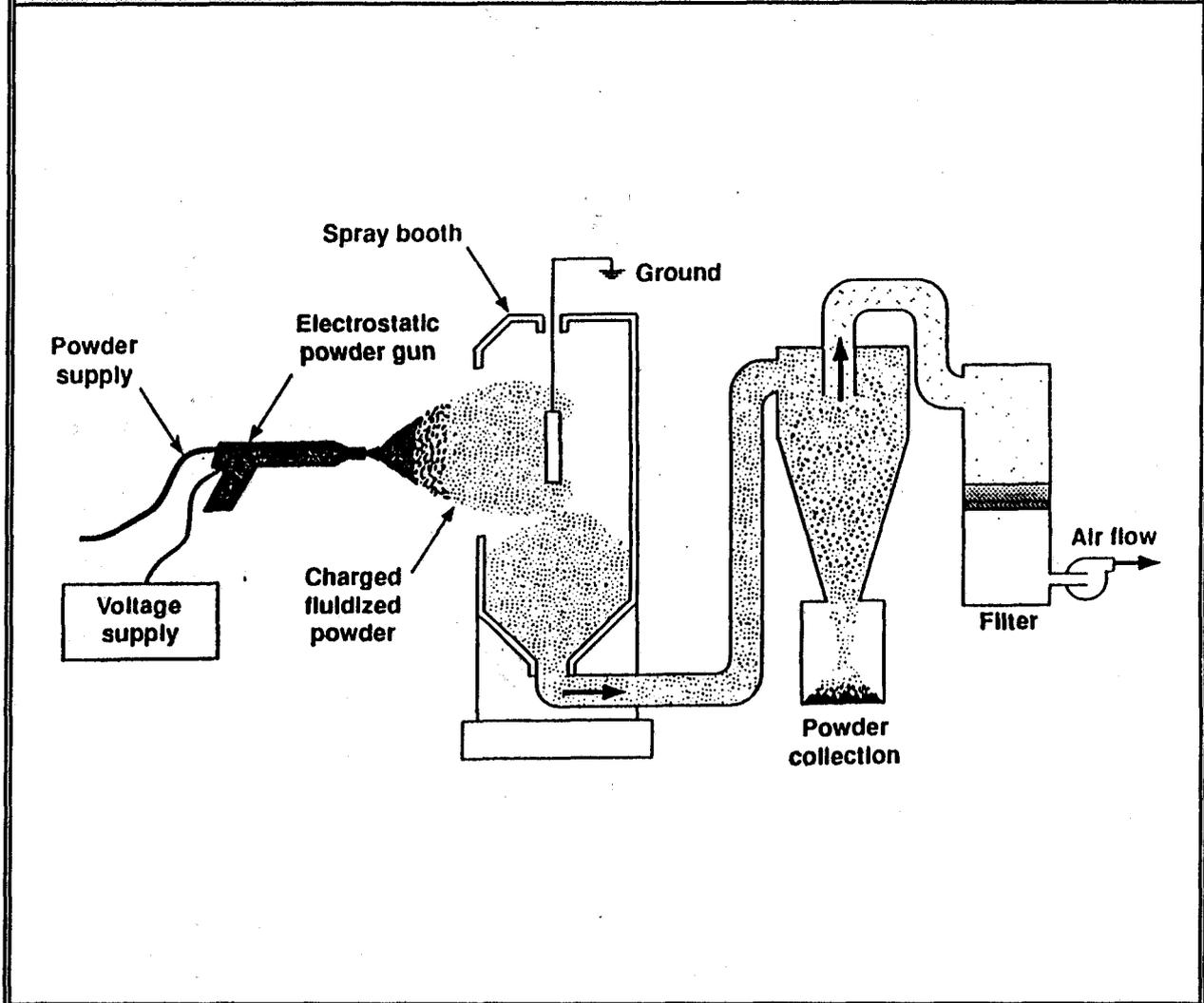
With the electrostatic spray gun (Figure 3-8), powder is supplied pneumatically using air as the carrier medium. The spray guns are used to impart the charge to the powder being sprayed and to control the direction and amount of powder being sprayed. Electrostatic forces ensure that the powder adheres properly to the surface of the part to be coated. Excess powder is collected and recycled (Figure 3-9). The coated objects are then heated in a curing oven to fuse the powder to the surface.

**FIGURE 3-8
POWDER COATING BY ELECTROSTATIC SPRAY GUN**



Source: *Spray Painting: Improvements and Alternatives*

**FIGURE 3-9
POWDER COATING RECOVERY SYSTEM**

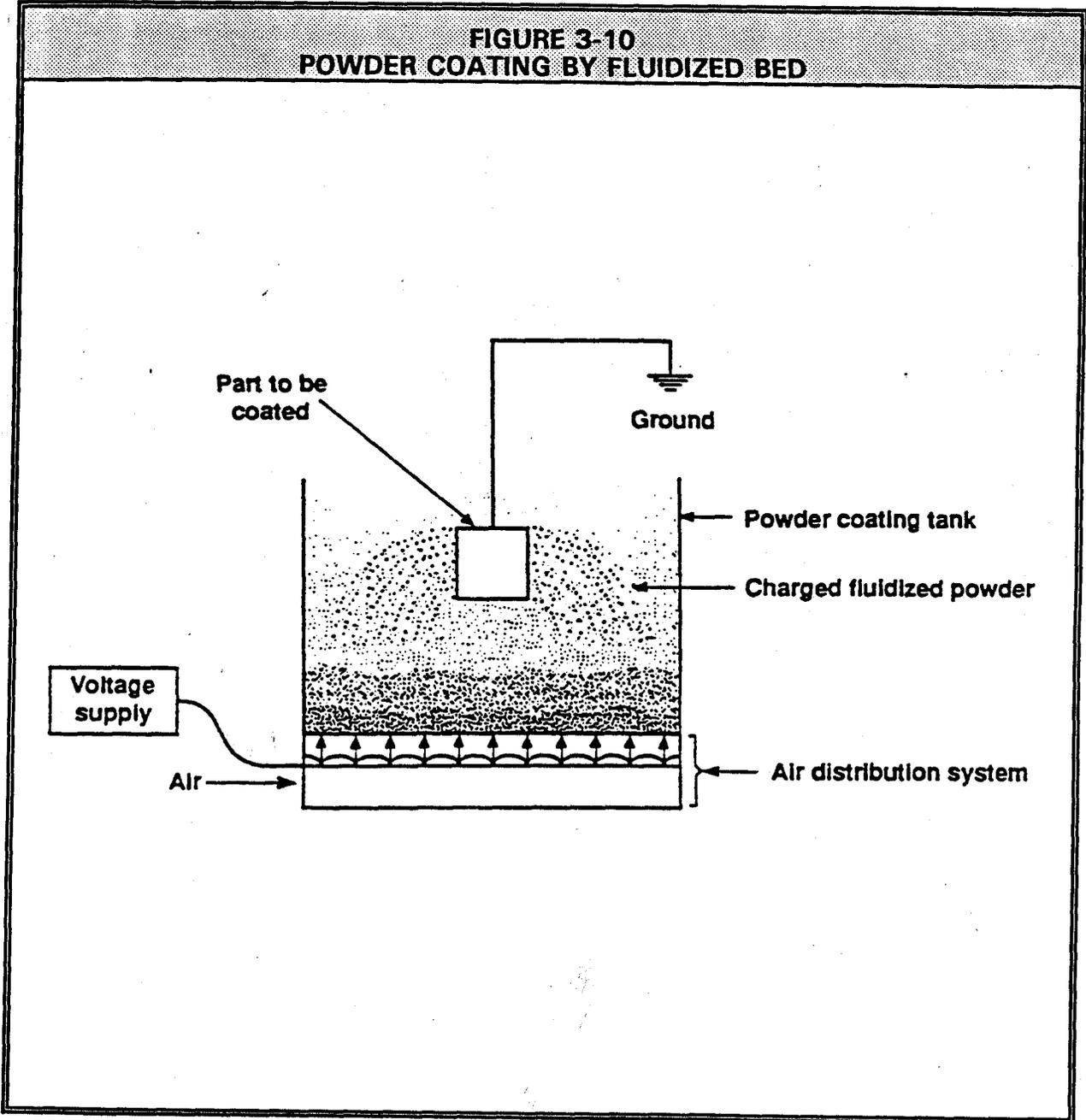


Source: *Spray Painting: Improvements and Alternatives*

With a fluidized bed, the part to be coated must first be heated before immersion in the bed. Next, as air is introduced at the bottom of a bed of powder, the part is immersed. As the particles of powder strike the hot surface of the part, they melt and coalesce to form a thin film on the part. As the part cools, the powder solidifies to form a coating. In electrostatic fluidized beds (Figure 3-10), the fluidized powder is charged. When an unheated part is immersed in the bed, a film of powder is held in place by electrostatic forces. The part, with powder coating, is then heated in an oven to melt and cure the coating.

Advantages of powder coatings include efficient material use and high transfer efficiency, elimination of solvent use and associated waste disposal and emission concerns, and ease of operation and maintenance. Drawbacks include the potential hazards associated with handling heated parts and some difficulty in applying thin coatings.

**FIGURE 3-10
POWDER COATING BY FLUIDIZED BED**



Source: *Spray Painting: Improvements and Alternatives*

Table 3-1 provides a summary of coating methods.

TABLE 3-1 SUMMARY OF COATING APPLICATION PROCESSES		
Method	Transfer Efficiency	Wastes Generated
Spray coating		Coating overspray, filters and coating sludge from air pollution control, equipment cleaning wastes, scrubber water
Conventional	30 - 40	
HVLP	70 - 90	
Airless atomization	40 - 50	
Air-assisted atomization	40 - 50	
Electrostatic	70 - 90	
Dip coating	95 - 100	Cleaning waste when coating in dipping tank is changed
Electrocoating	95 - 100	Cleaning waste when coating in tank is changed
Flow coating	95 - 100	Equipment cleaning waste when coating is changed
Curtain coating	95 - 100	Equipment cleaning waste when coating is changed
Roller coating	95 - 100	Equipment cleaning waste when coating is changed
Powder coating	95 - 100	Powder overspray that is collected and reused

3.2.4 Pollution Control

3.2.4.1 Air Pollution Control

Most coating operations are conducted in booths to confine overspray, remove particulate matter, and exhaust solvent-laden air. *Dry booths* utilize disposable filters, rolls of filter media, or staggered plates to capture most of the coating overspray. In *waterwash booths*, exhaust air is drawn through a water curtain or through a metal floor grating into a pan of water to collect the overspray. *Powder coating booths* collect coating powders for reuse. Exhaust from dry and waterwash booths typically contains high humidity, sticky coating particulate, and VOCs.

With the air toxic provisions of the 1990 Clean Air Act Amendments, the use of additional controls is necessary for many larger coating operations and a growing number of small-to-medium sized operations. When VOC control is required, it is generally necessary to install secondary particulate filtration prior to VOC control. Typical control technologies include dry filter houses, wet electrostatic precipitators, or wet scrubbers. A number of control technologies are available to control the

emissions of VOCs. Recovery methods include adsorption and condensation. Destruction technologies include incineration and biofiltration.

3.2.4.2 Wastewater Treatment

As water is recirculated in a waterwash booth, tacky coating resins must be removed to prevent clogging of pipes and pumps. A number of chemical treatment methods are available to concentrate the sticky coating sludge. After chemical treatment, the sludge must be removed mechanically by skimming or centrifugation. The selection of the chemical treatment program and the sludge removal system is dependent on the type of coating, type of booth, and budget constraints.

Water leaving the waterwash booth may still have a high pH (if caustic-based treatment chemicals were used) or high dissolved solids (if a polymer was used) and may require additional treatment. The wastewater treatment system needed will depend on the characteristics of this wastewater stream as well as wastewater streams from other plant processes (e.g., electroplating, anodizing, cleaning, etc.).

3.3 CURING

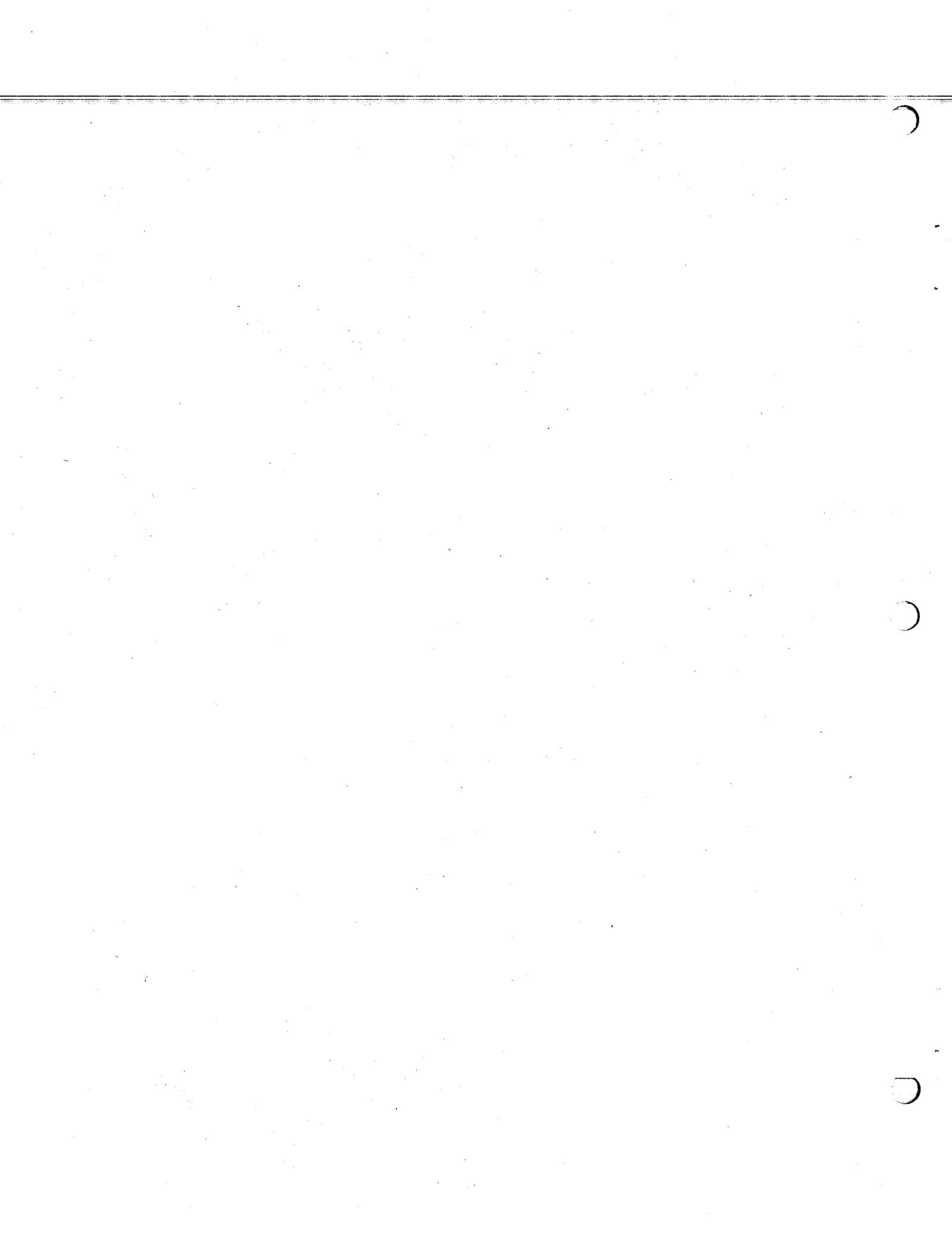
Once a coating is applied to a surface, a curing process takes place that converts the fluid or resinous coating binder into a hard, tough, and adherent film. The curing process is dependent on whether the coating contains a convertible or nonconvertible binder. If the binder is convertible, a chemical reaction occurs during curing, converting the coating to a solid film that is no longer soluble in its original solvent component. Coatings made with nonconvertible binders do not undergo chemical reaction upon curing. Rather, as they dry, solvent evaporates and, the resulting films remain soluble in the original solvent component.

For coatings with convertible binders, curing can take place through ambient air drying, baking, or chemical reaction. Additional curing techniques include ultraviolet radiation, infrared radiation, and irradiation with electron beams.

With the exception of radiation curing, wastes from curing typically include VOC emissions. Radiation curing techniques generally lack VOC emissions because little or no VOCs are used in radiation curable coatings.

3.4 EQUIPMENT CLEANUP

Coating application equipment (e.g., spray guns and hoses, tanks, rollers, etc.) must be cleaned after each use to prevent dry coating residues and to prevent contamination between coating changes. Equipment cleaning is a major source of waste generation during the application of coatings. Wastes include spent organic solvents, aqueous cleaners, wastewater, and coating sludge. As a general rule, solvent-based coatings require solvents for clean-up, while water-based coatings can be cleaned with less toxic aqueous solutions.



4.0 POLLUTION PREVENTION OPPORTUNITIES

Over the past few decades, environmental disasters have made Americans more aware than ever before of the harmful effects of hazardous and toxic wastes. As a result, regulators and industry alike have focused on control and cleanup of wastes to prevent risks to the environment and human health. While these control and cleanup efforts were certainly steps in the right direction, this approach focused on treating or disposing of wastes *after they were produced*.

Now, both government and business are turning their attention to preventing or minimizing the production of waste at its source. In general, the pollution prevention approach follows the hierarchy illustrated below.

- Source Reduction
- Waste Recycling
- Waste Treatment
- Waste Disposal

The first priority in this hierarchy is source reduction, the minimization or elimination of wastes at the source, usually within the production process. Source reduction should not be confused with volume reduction practices such as dewatering or compaction of waste. Key source reduction practices include:

- Process modifications
- Feedstock substitutions
- Improvements in feedstock purity
- Improved housekeeping and management practices
- Increased machinery efficiency
- Use or reclamation of wastes within a process.

Obviously, source reduction practices such as these can reduce waste generation, but in most cases cannot totally eliminate the waste. For the remaining wastes, generators should first look to waste recycling (i.e. solvent recovery, waste exchanges), next to on- or off-site waste treatment, and finally as a last resort, to waste disposal options.

This section provides a number of opportunities for reducing waste generation during metal cleaning and coating, while Section 5.0 outlines several recycling opportunities.

4.1 WASTE REDUCTION OPPORTUNITIES DURING METAL CLEANING

This section discusses opportunities to reduce waste generation for each of the cleaning methods described in Section 3.1. The first priority during metal parts cleaning is to explore opportunities to reduce solvent use and associated solvent wastes.

4.1.1 Waste Reduction During Solvent Cleaning

The recommended strategy for developing effective solvent pollution prevention options for metal parts cleaning operations relies on a systematic exploration of the following sequence of steps:

1. Avoid the need to clean.
2. Select the least hazardous solvent.
3. Maximize cleaning efficiency.
4. Segregate cleaning wastes.
5. Maximize recycling and reuse (See Section 5.1.1).

Table 4-1 provides a list of the most common waste minimization practices which can be applied to solvent wastes from metal parts cleaning.

**TABLE 4-1
POLLUTION PREVENTION PRACTICES FOR
METAL PARTS CLEANING SOLVENTS**

Avoid or Reduce Need To Clean	Re-examine Important Cleaning Considerations	<ul style="list-style-type: none"> • Composition of the part • Characteristics of the contaminant • Source of the contaminant • Degree of required cleanliness
	Convert Upstream Manufacturing Processes	<ul style="list-style-type: none"> • Employ "low-waste" fabrication technologies • Substitute chemicals used in upstream presses • Upgrade deburring operations
Use Alternative Cleaning Methods	Substitute Less Toxic Media For Solvents	<ul style="list-style-type: none"> • Replace with high pressure-hot water or steam • Replace with aqueous cleaners • Use less toxic organic solvents (terpenes, aliphatic hydrocarbons, alcohols, esters, amines) • Replace with mechanical alternatives
Extend Solution Life	Re-examine Operating Procedures	<ul style="list-style-type: none"> • Pre-clean parts before solvent cleaning • Prevent contamination of cleaning solvent • Prevent "drag-in" of water • Use appropriate make-up solution • Promptly remove solids • Use two-stage cleaning • Use ultrasonic or mechanical agitation • Monitor solvent quality and composition
	Reduce Drag-out Losses	<ul style="list-style-type: none"> • Reduce the concentration of bath constituents • Reduce speed of workpiece withdrawal • Properly position the workpiece on the cleaning rack • Use air knife to blow-off drag-out • Recover and recycle drag-out
	Reduce Evaporative Losses	<ul style="list-style-type: none"> • Install lids on tanks • Increase freeboard height • Avoid draft over the degreaser • Control amount of heat supplied to vapor degreaser • Adjust cooling • Check water jacket for proper flow and temperature • Install freeboard chillers in addition to cooling jackets • Avoid spraying parts above vapor zone or cooling jacket • Reduce exhaust velocities • Eliminate wind tunnels • Move the work slowly • Allow proper drainage before removing item • Bring parts up to temperature before removal • Dewater the solvent • Avoid overloading or inserting oversized items into tank • Routinely inspect for and repair leaks • Consolidate cold cleaning into centralized degreaser • Locate cold cleaning tanks away from heat sources
Recycle	Spent Solvents	<ul style="list-style-type: none"> • Downgrade solvents • Reduce the number of different solvents used • Segregate • Remove solids • Use emulsion or dispersion breaking chemicals • Recover dissolved and emulsified organics • Use industrial heat pumps for solvents recovery • Use other distillation, condensation, and membrane separation technologies
	Solvent Air Emissions	<ul style="list-style-type: none"> • Activated Carbon Recovery • Activated Carbon Fiber Recovery • Liquid Absorption • Condensation • Industrial Heat Pumps

4.1.1.1 Avoid or Reduce the Need to Clean

The first priority in efforts to reduce solvent waste from metal parts cleaning is to carefully re-examine the need for cleaning. This may seem unnecessary, but many metal cleaning operations have developed cleaning procedures that far exceed the actual cleaning requirements -- procedures that generate excessive waste.

Such examination may also serve to identify upstream manufacturing processes that can be modified in order to reduce, or even eliminate, the need for cleaning.

Re-Examine Important Cleaning Considerations

Prior to selecting cleaning chemistry and equipment, it is necessary to understand four important cleaning considerations, namely:

- The composition of the part
- The characteristics of the contaminant
- The source of the contaminant
- The degree of required cleanliness.

Composition of the Part

The composition of the part relates to its configuration, size, weight, function, porosity, substrate, and quantity. The size and shape of the work pieces seldom influence the type of cleaning chemistry used, but may determine the method of cleaning and handling. For example:

- Parts with high porosity, rough surfaces, permanent overlapping joints, and/or blind holes can retain cleaning solution and cause corrosion.
- Some metals, such as aluminum and alloys containing magnesium, lithium, and zinc, require special consideration because of their sensitivity to attack by certain chemicals.

Contaminant Characteristics

The efficiency of cleaning is highest when the chemistry has an affinity for the contaminant to be removed. Typical contaminants that must be removed by metal parts cleaning processes can be classified into seven groups:

- Particulate contamination - microscopic contaminants, usually affect only high quality cleaning.
- Thin film chemical contamination - contaminant sources include outgassing from lubricants, adhesives, coatings, and polymeric and elastomeric materials. Contamination also occurs from finger prints, machining fluids, coolants, and packaging.
- Pigmented compounds - may require removal from substances such as: whiting, lithophone, mica, zinc oxide, bentonite, flour, graphite, and soap-like materials.

- Unpigmented oil and grease - such as drawing lubricants, rust preventative oils and quenching oils.
- Forming lubricants and machining fluids - include mineral and fatty oils; conventional or heavy duty soluble oils with sulfur or other compound added; and chemical cutting fluids.
- Polishing and buffing compounds - can be classified into three subgroups:
 - Liquids -- mineral oils and oil-in-water emulsions, or animal and vegetable oils with abrasive materials.
 - Semi-solids -- oil-based materials containing abrasive and emulsions, or water-based materials containing abrasive and dispersing agents.
 - Solids -- grease containing stearic acid, hydrogenated fatty acids, tallow, petroleum waxes, and abrasive materials, etc.
- Miscellaneous surface contaminants - hand oils, shop dirt, airborne dust, fingering grease and metal pieces, lapping compounds, etc.

Contaminant Source

The source of the contaminant(s) must be determined so that potential cleaning modifications can be evaluated. The following basics should be checked as part of this evaluation:

Are the contaminants:

- received as raw materials?
- produced in general machining operations?
- produced in forming/stamping operations?
- produced in subassembly?
- received with vendor parts?

In many cases, the answers to these questions will help to identify the upstream manufacturing steps that contribute the most to your cleaning requirements. Suggestions for converting upstream manufacturing processes to reduce subsequent solvent cleaning requirements are provided in a later section.

Degree of Required Cleanliness

Once the contaminants and their sources are determined, the required degree of cleanliness has to be re-examined. The goal of this examination is to determine the minimum level of cleanliness acceptable to meet performance requirements. Several standard tests can be used to determine the cleaning ability of any alternative cleaning process, including:

- Visual inspection
- Electron or optical microscopy
- Microchemistry characterization
- Tissue paper test
- Acid copper test

- Residue level test
- Atomizer test
- Surface energy test
- Kerosene viewing of water break
- Radioactive tracers and fluorescent dyes
- Gravimetric testing
- Particulate contamination evaluation.

(source: WRITAR)

Convert Upstream Manufacturing Processes to Reduce Subsequent Solvent Cleaning Steps

Perhaps the most effective method of source reduction and solvent waste elimination is to convert manufacturing processes to reduce or eliminate solvent cleaning steps.

The following process changes reduce later waste producing finishing steps, such as solvent cleaning.

Employ "low-waste" metal cutting, forming, and bonding technologies

In the manufacture of a variety of metals, new machining, cutting, forming, and bonding technologies that provide source reduction benefits include:

- Electrical discharge machining
- Waterjet cutting
- Plasma-arc cutting
- Laser cutting
- Electrochemical machining
- Electromagnetic forming
- Induction bonding.

In many cases, these technologies can reduce or eliminate the need for coolants, and reduce or eliminate subsequent metals parts cleaning requirements.

Substitute materials used in metal cutting, forming, and bonding

Substituting materials used in metal cutting, forming, and bonding processes can not only reduce waste generated from these manufacturing steps, but may also reduce subsequent cleaning requirements. Examples include:

- Use high quality metalworking fluid
- Use synthetic metalworking fluids
- Use lime or borax soap
- Use gases for cooling.

Upgrade deburring operations

In some cases, vapor degreasing may be eliminated by upgrading existing deburring operations and rescheduling the parts processing so that abrasive deburring is the final cleaning step for the vast majority of parts produced. For example, one facility that formerly used trichloroethane degreasing upgraded deburring operations by:

- Adding a wet sander and modifying the existing vibratory tumbling machines.
- Replacing the oil-based lubricant used in the old system with a water-based lubricant to make removal of the forming lubricants easier.

The new water-based system now cleans and deburrs parts simultaneously and does not require further vapor degreasing.

4.1.1.2 Use Alternative Cleaning Methods

Many firms have been successful in substituting less toxic cleaning media for toxic solvents. The alternatives include:

- Hot water or steam
- Aqueous cleaners
- Mechanical cleaning
- Less toxic organic solvents

Discussion of each substitution approach is provided in the following sections.

High-Pressure Hot Water or Steam

The simplest aqueous cleaner is water, which can be used in combination with mechanical or ultrasonic agitation. Hot water high-pressure spray systems are quite effective at removing caked-on dirt and grime and have been successfully tested for certain critical cleaning requirements. Similarly, steam cleaning can also be used to clean grease and oils from metal parts.

For example, at Fort Lewis, Washington, the old procedure of cleaning engine compartments with solvents, steam, and detergents was replaced with high-pressure hot-water washers.

With the old procedure, cleaning with solvents, steam, and detergents:

- It was impossible to separate the oil/water emulsion in a simple oil/water separator.
- Solvents contaminated both the water and the oil, rendering both a hazardous waste.
- Disposal costs for these hazardous wastes were \$84,000 per year plus transportation.

With the new high-pressure, hot-water system:

- The need for detergents or solvents has been eliminated.
- Both water usage and maintenance have been reduced.
- Since the oil and grease were no longer emulsified, a simple oil/water separator was sufficient to treat this wastewater.

- An additional 46,000 gal of used oil was recovered and sold to a recycler for \$10,800.

Aqueous Cleaners

Aqueous cleaning has traditionally been used to remove inorganic-based materials from metals. Recently however, aqueous systems have been developed that remove organic contaminants, permitting the successful substitution of aqueous cleaners for solvents. For instance, a company originally used trichloroethylene (TCE) to wash their small parts prior to assembly. The company replaced the TCE wash unit with a modified Hobart dishwasher, which uses hot water sprays and aqueous cleaners to remove the machine oils. Hot air was then used to dry the parts immediately after they were cleaned.

The cleaning action of aqueous cleaners relies mainly on displacement of contaminants rather than dissolving them as is the case with organic solvents.

Evaluate wastewater quality issues

Wastewater quality issues and recyclability aspects must be carefully evaluated when selecting an aqueous cleaner. Many "safe substitutes" employ the use of additives to accomplish cleaning requirements. Because some of these additives may present health and safety concerns of their own, Material Safety Data Sheets (MSDSs) need to be evaluated. Additional information regarding hazardous constituents and the BOD and COD of solutions with additives may be needed as well.

Many suppliers can formulate cleaners to meet your needs to address issues such as corrosivity, flammability, and health effects, etc.

Determine if organic solvents are a component of your aqueous cleaner

Some aqueous cleaners include small concentrations of organic solvents to enhance cleaning performance. Again, carefully review the MSDSs and identify the types and amounts of any organic solvents used.

Contact suppliers and test aqueous cleaning alternatives

Solvent cleaning is sometimes used because a previous aqueous cleaning attempt was unsuccessful. Before committing to solvent cleaning, investigate the compounds to be removed. Suppliers of metal processing chemicals can often recommend aqueous cleaner substitutes. Naturally, testing of a number of substitutes is recommended and aqueous cleaner manufacturers should also be contacted for specific recommendations. A suggested testing method is provided in Table 4-2.

TABLE 4-2
HOW TO SELECT AN AQUEOUS CLEANER

1. Review cleaner composition. Hazardous or undesirable components are identified on material safety data sheets. Many candidate cleaners can be eliminated on this basis.
2. Identify contaminants to be cleaned from parts and obtain samples of each.
3. Apply each contaminant to representative metal panels and immerse in each candidate cleaner in laboratory-scale cleaning tanks. Use manufacturer's recommendations for concentration and temperature and provide mechanical agitation. After periods of 5, 10, and 15 minutes, remove panels from bath, rinse, and evaluate cleanliness. Cleanliness can be ascertained by (a) water break, (b) fluorescence under UV light (applicable for contaminants that fluoresce), and (c) by immersing in a cupric chloride solution and observing uniformity of copper deposited.
4. If a contaminant was cleaned (from Step 3), lower the temperature and re-test until the minimum effective temperature is identified. Also determine the minimum effective cleaner concentration in a similar manner. If the contaminant from Step 3 was not cleaned, increase temperatures and concentrations to identify minimum effective parameters. These data will permit selecting the optimum operating conditions for any contaminant or mixtures of any of the cleaners evaluated.
5. Using a series of standard tests, determine etch rates, staining characteristics, effects on coatings' adhesion, and corrosion characteristics.
6. Evaluate cleaner performance including tank maintenance, recyclability, and disposal requirements in a pilot plant-scale tank prior to full scale implementation.

Selection process developed by General Dynamics/Fort Worth Division (Evanoff et al 1987)

Less Toxic Organic Solvents

Toxic solvents can often be replaced with safer alternatives. Prerequisites include:

- Low toxicity
- Low flammability
- Low vapor pressure
- High solvency
- Low cost.

Table 4-3 provides some suggested alternatives for hazardous industrial solvents and cleaning agents currently in use (source: Pollution Prevention Review/Summer 1991). Additional information regarding solvent toxicity can be found in Appendix A.

**TABLE 4-3
SUGGESTED SOLVENT ALTERNATIVES**

SOLVENT	APPLICATION	POSSIBLE SUBSTITUTE
CFCs and TCA	Industrial degreasing and cleaning, and removal of flux from electronic circuit boards	<ul style="list-style-type: none"> • Semi-aqueous emulsions: surfactants in organic solvents followed by water rinse • Aqueous emulsions: organic or inorganic surfactants in water • Heavy aliphatic hydrocarbons • N-methyl pyrrolidinone (NMP) and its derivatives • Terpenes • N-butyl butyrate • Alcohols, ethers, esters
Aromatic Hydrocarbons (benzene, toluene, xylene)	Solvents in agricultural, chemical, coatings, adhesives, and polymers	<ul style="list-style-type: none"> • N-alkyl pyrrolidinones (NAP) • Terpenes • Aliphatic hydrocarbons • Amines, ethers, esters, alcohols
Ketones (acetone, methyl ethyl ketone, methyl isobutyl ketone), and halogenated hydrocarbons	Cleaning agents in electronic, painting, coating, chemicals and printing	<ul style="list-style-type: none"> • Surfactants in water, combined with mechanical scrubbing • Diabasic esters (DBE) • N-methyl pyrrolidinone (NMP) and derivatives • Terpenes • Heavy aliphatic hydrocarbons • Alcohols
Ethylene glycol ethers	Photoresist thinner for integrated circuit manufacture	<ul style="list-style-type: none"> • Propylene glycol mono-methyl ether acetate • Ethyl-3-ethoxypropionate (from propionic acid) • Ethyl lactate (from lactic acid)

Common organic solvents can be classified into the following general categories:

- Terpenes
- Soy-based solvents
- Aliphatic hydrocarbons
- Alcohols
- Esters
- Amines
- Glycol ethers

- Ketones and aldehydes
- Aromatic hydrocarbons
- Halogenated hydrocarbons
- Chlorofluorocarbons (CFCs)
- Hydrochlorofluorocarbons (HCFCs)
- Hydrofluorocarbons (HFCs), and
- Fluorocarbons (FCs)

The following provides a brief description and example of common solvents for each category.

Terpenes

Terpenes, essentially oils isolated from plants through gentle heating or steam distillation, are especially promising as potential substitutes for many toxic 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 Regulations. Limonenes have fared favorably in comparison testing against solvents, solvent emulsions, and alkaline cleaners for removal of heavy greases, oils and oily deposits. Terpenes include:

- D-limonene
- Anethole
- Alpha-pinene
- Beta-pinene
- Alpha-terpinene
- Beta-terpinene
- Terpinolene
- Dipentene (di-limonene).

Surfactants added to terpenes form emulsified cleaning compounds that are water rinseable.

Reported disadvantages of terpenes include difficulty in separating oily wastes 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.

Soy-Based Solvents

Soy-based solvents, derived from the oils of soy beans, offer another potential alternative to toxic solvents. These solvents have been used successfully in parts washers and for other degreasing applications. However, they leave a thin film of oil that, while offering rust protection, interferes with surface coating. Manufacturers are exploring the addition of surfactants to make the soy-based solvents water rinseable.

Aliphatic Hydrocarbons

Aliphatic solvents include a wide range of solvents used for all sorts of hard surface cleaning. Most are not listed as hazardous air pollutants (HAPs), and therefore

generally are preferred over many ketones, aromatic hydrocarbons, and halogenated hydrocarbons.

Aliphatic hydrocarbons, however, have flashpoints lower than 140°F, which classifies them as EPA hazardous. Their emissions are also regulated because of their VOC content. Common aliphatic carbon solvents, ranked from low to high hazard, include:

- Mineral spirits (petroleum distillates; petroleum naphtha)
- Stoddard solvent
- Turpentine
- Kerosene
- Heptane
- Hexane.

Alcohols

Many common alcohols may also be used as cleaning solvents. As with aliphatic hydrocarbons, most are not listed as HAPs, and therefore may be preferred over many ketones, aromatic hydrocarbons, and halogenated hydrocarbons for health safety reasons.

However most alcohols are very flammable (even more so than many aliphatic hydrocarbons) with flashpoints in the 60°F range, which classifies them as EPA hazardous for ignitability. Their emissions are also regulated because of their VOC content. Common alcohol solvents, ranked from low to high hazard, include:

- Ethyl alcohol (ethanol; anhydrous alcohol)
- Isopropyl alcohol (isopropanol; rubbing alcohol)
- Sec-butyl alcohol (2-butanol)
- Isobutyl alcohol (isobutanol)
- N-butyl alcohol (n-butanol)
- Methyl alcohol (methanol)
- Ethylene glycol.

Esters

Esters are common organic solvents, also used as additives in aqueous cleaners. As with aliphatic hydrocarbons and alcohols, most are less toxic, and, therefore, may be preferred over many ketones, aromatic hydrocarbons, and halogenated hydrocarbons for health safety reasons. Common ester solvents include:

- Gamma-butyrolactone (BLO)
- Glyco ether acetate
- N-butyl butyrate
- Isobutyl isobutyrate
- Ethyl lactate
- Propylene glycol mono-methyl ether acetate
- Ethyl acetate
- Isopropyl acetate
- Butyl acetate.

Amines

Common organic solvents containing nitrogen, amines are also frequently used as additives in aqueous cleaners. Some amine solvents are less toxic, and, therefore, may be preferred over many ketones, aromatic hydrocarbons, and halogenated hydrocarbons for health safety reasons. These include N-alkyl pyrrolidine (NAP) (pyrrolidinone) and N-methyl-2-pyrrolidine (NMP).

Some amine solvents, however, are highly toxic, and care must be used in selecting the appropriate solvent. Common toxic amine solvents include morpholine (diethyleneimide) and pyridine. In addition, high nitrogen concentrations can cause problems with wastewater discharges.

Glycol Ethers

Glycol ethers are common solvents used as an active ingredient in aqueous cleaners. This solvent group is being phased out since reproductive defects have been linked to their use, and some have been listed as HAPs. Common glycol ethers include ethylene glycol monoethyl ether (cellosolve; 2-ethoxyethanol) and ethylene glycol monobutyl ether (butyl cellosolve).

Ketones and Aldehydes

Often used in paint and resin related cleaning, these solvents pose both ignitability and toxicity hazards. Several are listed as HAPs, and their emissions are also regulated because of their VOC content. Common ketone or aldehyde solvents include:

- Acetone
- Methyl ethyl ketone
- Methyl isobutyl ketone
- Cyclohexanone
- Formaldehyde (formalin).

Aromatic Hydrocarbons

Although some may be used in specialized applications, aromatic hydrocarbons are rarely used for general cleaning due to their known toxicity and very low flashpoints. Most are listed as HAPs, and their emissions are also regulated because of their VOC content. Common aromatic hydrocarbon solvents include:

- Xylene
- Toluene (methyl benzene)
- Phenol
- Benzene.

Halogenated Hydrocarbons

Halogenated (chlorinated) hydrocarbons have been widely used for a variety of industrial solvent applications, but are being phased out due to numerous health and environmental risks, including:

- Toxicity and carcinogenicity -- most have been listed as HAPs
- High VOC emissions contributing to smog formation
- Contribution to atmospheric ozone depletion.

Common halogenated hydrocarbons include:

- Methylene chloride (dichloromethane)
- 1,1,1 - trichloroethane (methyl chloroform; TCA)
- Chlorobenzene
- Trichloroethylene
- Tetrachloroethylene (perchloroethylene)
- 1,1,2 - trichloroethane
- Carbon tetrachloride (tetrachloromethane)
- Chloroform
- 1,1,2,2 - tetrachloroethane.

Chlorofluorocarbons (CFCs)

Chlorofluorocarbons (CFCs) offer good solvency and rapid evaporation. They are widely used in vapor degreasing and critical cleaning as they dry with no detectable residue. However, these solvents are being phased out because of their contribution to atmospheric ozone depletion.

Hydrochlorofluorocarbons (HCFCs)

Hydrochlorofluorocarbons (HCFCs) are considered only "interim" substitutes for CFCs, because they also contribute to atmospheric ozone depletion -- but at a lower rate than CFCs.

Hydrofluorocarbons (HFCs) and Fluorocarbons (FCs)

Because they do not contain chlorine, hydrofluorocarbons (HFCs) and fluorocarbons (FCs) do not deplete the ozone layer, and probably do not contribute to smog formation either. However, these compounds have long atmospheric lifetimes and, therefore, would be expected to contribute significantly to global warming may be regulated in the future.

Mechanical Alternatives

The use of 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. Other abrasive blasting materials, such as carbon dioxide pellets, are also used for metal parts cleaning and paint stripping.

Mechanical alternatives can also be used to dry cleaned parts. For example, air blast systems utilizing a high velocity air jet can be used instead of solvents to dry parts following a water rinse operation.

High Quality Cleaning Applications

High quality precision cleaning is most commonly applied in the following industries:

- Printed circuit boards manufacturing
- Semiconductor industry
- Capacitors and electronic components manufacturing
- Medical equipment manufacturing

- Small diameter tubing manufacturing
- Instruments.

These operations typically require cleaning solvents of high purity and rapid evaporation rates with low residuals. The traditional chemicals for these applications, such as chlorofluorocarbons (CFCs) and chlorinated solvents, are being phased out because of their toxicity and ozone depletion potential. Likewise, another group of commonly used precision cleaning solvents, ethylene glycol ethers, are being phased out since reproductive defects have been linked to their use.

Examples of successful substitutes for highly toxic and environmentally harmful solvents for precision cleaning include:

- Propylene glycol mono-methyl ether acetate has only a slightly different atomic structure than the ethylene glycol ethers, and appears to be metabolized differently in animals.
- Ethyl-3-ethoxypropionate is derived from propionic acid, similar to acetic acid.
- Ethyl lactate is a derivative of a lactic acid produced in mammals during normal respiration.
- n-butyl butyrate, a substance that occurs naturally in cantaloupes, other melons, peaches, and plums but is formulated chemically by Dow Chemical Co.

These substances have been studied in animals and have demonstrated less toxicity than ethylene glycol ethers and many of the chlorinated solvents commonly used in precision cleaning.

Substitutes that may be used for high quality precision cleaning include:

- Aqueous Cleaning
- Semi-Aqueous Cleaning
- Hydrocarbon Cleaning
- Abrasive Cleaning
- Non-Chelated Cleaners
- No Clean System
 - Low Solids Fluxes
 - Inert Gas Wave Soldering.

Aqueous Cleaning

Industry has traditionally used aqueous cleaning to remove inorganic-based materials from metals. Recently, however, aqueous systems have been developed that remove organic contaminants. These systems use saponifiers and emulsifiers as additives to enhance the cleaning capabilities of the solution. Use of water-based flux may be necessary to use this technology with electronic assemblies.

For critical cleaning applications where hard water deposits may result in staining, use of demineralized or deionized water is recommended. For example, hot deionized water has been successfully tested as a replacement for CFC-113 in certain critical cleaning applications in the manufacture of disk drives in the electronic industry.

No one drop-in substitute aqueous cleaning solution is available for all precision cleaning applications. However, many alternative cleaning technologies are available for evaluation. To find the right aqueous-based cleaner for each operation, work with vendors of aqueous cleaners and equipment. See section 3.1.2 for further information on aqueous cleaning.

Semi-aqueous Cleaning

Semi-aqueous cleaning solutions combine terpenes or hydrocarbon with other additives. These cleaners effectively remove heavy grease, heavy manufacturing soils, adhesives, organics, and water-soluble soils. These cleaners work well with all common flux types and penetrate into narrow spaces making them effective in cleaning surface mount assemblies. See section 3.1.3 for further information on semi-aqueous cleaning.

Hydrocarbon Cleaning

Hydrocarbon cleaning includes oxygenated hydrocarbon formulations, usually aliphatic esters, or hydrocarbon-rich formulations. These cleaners have applications in electronics and precision cleaning and are commonly used to clean material on which water cannot be used due to corrosivity. These cleaners are combustible and require longer drying times. See section 2.3.4 for further information on hydrocarbon cleaning alternatives, including esters, alcohols, and others.

Abrasive Cleaning

Mechanical or abrasive cleaning methods generate less waste than other techniques. However, these methods can only be used before electronic components have been added to the boards. Abrasive blast uses plastic, ceramic, carbon dioxide, or harder media such as aluminum oxide to remove oxidation layers, old plating, paint and burrs from workpieces, and to create a smooth surface. See section 3.1.4 for further information on abrasive cleaning.

Non-chelated Cleaning

The use of non-chelated process chemicals instead of chelated chemical baths can reduce hazardous waste generation. The use of chelators in chemical process baths allows metal ions to remain in solution beyond their normal solubility limit and enhances cleaning, metal etching, and selective electroless plating.

However, once the chelating compounds enter the waste stream, more chemicals must be used for waste treatment, and more sludge is produced. Reducing agents such as ferrous sulfate can be used to treat wastewaters that contain chelators. However, one facility discovered that the iron present in the resultant sludge contributed approximately 32 percent to the total dry weight of the sludge.

Non-chelated alkaline cleaners are available. In addition, if chelators are required, the use of mild chelators can reduce the need for additional treatment of wastewaters. For example, EDTA is a mild chelator that only requires lowering the pH to below 3.0 to allow metals to precipitate.

No Clean Systems

Several processes have been developed that, if implemented, would eliminate the need for cleaning fluxes applied prior to soldering printed circuit boards. Two of these processes are low solids fluxes and inert gas wave soldering.

- **Low Solids Fluxes** - The electronics industry has traditionally used rosin fluxes containing 15 to 35 percent solids for soldering of electronics assemblies. Low solids (1 to 10 percent rosin and/or resin) fluxes are available that, with proper application, leave little or no visible residue and may not need to be removed.
- **Inert Gas Wave Soldering** - This soldering operation is performed under a nitrogen atmosphere, applying carboxylic acid activators through ultrasonic injection. Since the system does not use conventional rosin or resin fluxes, oxide formation is reduced and post-solder cleaning is eliminated.

4.1.1.3 Extend Solution Life

Extending the useful life of a cleaning solvent will reduce the quantity of solvent wasted and the quantity (and cost) of replacement solvents. Three significant operational areas should be evaluated, including:

- Implementing operating procedures to maximize solution life
- Reduce drag-out losses
- Reduce evaporative losses.

Each of these areas of operations are discussed more fully in the following sections.

Implement Operating Procedures to Maximize Solution Life

Several pollution prevention practices can be implemented during the operation of solvent cleaning systems to maximize solution life and minimize losses. Suggestions include:

- Pre-clean parts before solvent cleaning
- Prevent contamination of the solvent
- Prevent "drag-in" of water
- Use appropriate make-up solution
- Promptly remove solids
- Use two-stage cleaning
- Use ultrasonic or mechanical agitation
- Monitor solvent quality and composition.

Pre-clean parts before solvent cleaning

- Use dry pre-cleaning methods such as manually cleaning the part with a wire brush prior to solvent cleaning to remove the bulk of the dirt.
- Use high velocity, low volume spray wand to dislodge solids -- but be careful about water "drag-in."

Prevent contamination of cleaning solvent

- Reduce the number of different solvents used.
- Prevent drag-in from other processes -- very small quantities of one solvent (less than ¼ of 1 percent) added to a second solvent can create acid conditions.
- Cover tanks when not in use.

Prevent "drag-in" of water

- Contamination of chlorinated solvents with water can cause acid formation.
- Acid acceptance test indicates that the solvent is close to the point of becoming acidic, and specific stabilizers should be added.
- Water contamination increases diffusion of solvents increasing evaporative loss.
- The water separator should be cleaned and checked frequently for proper drainage.
- The temperature of the water exiting the condenser coils should be maintained at 90 to 100°F.
- 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.

Use appropriate makeup solution

- The solution can be tested, and reactivated by adding appropriate agents. Usually, the expense of analysis will be offset by the savings in solvent.
- Adding fresh solvent to boost the level of stabilizers is poor practice; rather the solvent should be analyzed and specific compounds added as required.
- Some leasing services will provide this maintenance service for the tanks you own.

Promptly remove solids

- Contaminants can dissolve into, or absorb useful solvent -- promptly removing solids can extend solvent life by 4 to 13 weeks.
- Remove solids from tank bottom if tank does not have heating elements.
- Install solids filter on slipstream.

- Organic soil contamination should not be allowed to exceed 10 percent for cold cleaning operations, and 25 percent for vapor degreasers -- acid formation can occur.

Use two-stage cleaning

- Allows the use of dirtier solvents to achieve the same degree of cleaning.
- Use the first tank to pre-soak parts in used "dirty" solvent.
- Use the second tank with fresh solvent to accomplish cleaning requirements.
- When solvent in second tank no longer achieves cleaning requirements, use that solvent to replenish the "dirty" solvent used in the first tank.
- Add fresh solvent to the second tank.

Use ultrasonic or mechanical agitation

Agitation allows the use of "dirty" solvent longer while achieving the same cleaning effectiveness. It may make possible the use of some cleaner that has reduced toxicity compared to current solvent.

Monitor solvent quality and composition

Because decisions to replace dirty solvent are often made arbitrarily, much solvent is disposed of prematurely.

- Solvents are typically replaced when the sludge concentration reaches 2 to 3 percent, although most solvents are still effective with up to 10 percent solids in them.
- Use solvent to the maximum. Refrain from having solvent replaced on a periodic basis. Rather replace only when absolutely necessary to achieve the cleaning power required.
- Solvent monitoring may be performed to ensure that the solvent is only replaced when it is no longer effective.
- Measuring the amount of light transmitted through a sample of dirty solvent is a reliable indicator of contamination. Such solvent "testers" are available from some solvent suppliers.

Reduce Drag-out Losses

Minimizing the drag-out reduces the amount of rinse water needed and the amount of the cleaning solution leaving the process, ultimately resulting in savings in raw materials and treatment/disposal costs. The amount of drag-out depends on the:

- Surface tension of the cleaning solution
- Viscosity of the cleaning solution

- Physical shape and surface area of the workpiece and rack
- Speed of workpiece withdrawal and drainage time.

Generally, drag-out minimization techniques include the following practices:

- Reduce the concentration of bath constituents
- Reduce speed of workpiece withdrawal
- Properly position the workpiece on the cleaning rack
- Use air knife to blow-off drag-out
- Recover and recycle drag-out.

Lower the concentration of bath constituents

Controlling the concentration of the solvent bath can reduce drag-out losses in two ways. First, reducing chemical concentrations in a process solution reduces the quantity of chemicals and the toxicity in any drag-out that occurs.

Secondly, greater concentrations of some chemicals in a solution increase the viscosity. As a result, the film adhering to the work piece as it is removed from the process bath is thicker and will not drain as easily. Lowering the concentration will result in:

- Lower solution viscosity
- Reduced rinsing requirement.

Reduce speed of workpiece withdrawal

In many cases the cleaning process is not the limiting factor for overall production capacity, and a few more minutes can be spent cleaning parts without affecting production. In such cases, the speed of workpiece withdrawal should be reduced, and ample drainage time allowed. For example:

- 30 seconds usually allows most drag-out to drain back to the tank.
- 10 seconds still permits good drag-out recovery in applications where quick drying is a problem.

Properly position workpiece on the rack

Proper positioning of the workpiece on a rack will facilitate the dripping of the drag-out back into the bath. This is best determined experimentally, although the following guidelines have been found to be effective.

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

Use air knife

A high pressure air knife can be installed to blow-off cleaning solution clinging to the workpiece.

Improve drag-out recovery

A drain board or empty tank positioned between a cleaning bath and rinse bath can capture the dripping solution and route it back to the bath.

Reduce Evaporative Losses

Pollution prevention practices to reduce solvent air emissions through equipment and/or operating procedure modifications include:

Install lids/silhouettes on tanks

All tanks should be covered when not in use. Covers that can be used during the cleaning process (known as "silhouette entries") are available and allow for even greater reduction in vapor loss. All covers should be designed to slide horizontally over the top of the tank, since this disturbs the vapor zone less than hinged covers. Covers can reduce solvent loss up to 55 percent.

Increase the freeboard space on tanks

An increased freeboard has been proven to decrease emissions. Early degreasers had a freeboard equal to one-half the tank width. When the U.S. EPA in the mid-1970s recommended a 75 percent freeboard, emissions were decreased up to 46 percent. Increasing the freeboard to 100 percent can provide an additional 39 percent reduction when air turbulence is present.

Avoid drafts over the degreaser

Fans, air conditioners, heaters, windows, doors, general plant air movement, and equipment movement can blow the vapor-air mixture out of the degreaser.

Locate the degreaser to minimize natural drafts or use baffles to prevent the vapors from being upset. Solvent loss reductions up to 30 percent can be realized.

Control the amount of heat supplied to vapor degreasers

Use the least amount of heat required to keep the solvent at a slow boil and to give adequate vapor production. Install thermostatic heating controls,

Adjust cooling

Regulate the cooling level either by adjusting the temperature of the cooling water or by altering its flow rate. The vapor level should balance at the midpoint of the condensing coil; a fluctuating vapor level pumps the vapor-air mixture out of the unit.

Check the water jacket for proper water flow and temperature

To prevent migration of hot vapor up the side walls and to prevent convection currents.

Install freeboard chillers in addition to cooling jackets

A second set of refrigerated coils can be installed above the condenser coils to chill the air above the vapor zone and create a second barrier to vapor loss. Reductions in solvent use of up to 60 percent have been realized. However, water contamination of the solvent can occur due to condensation buildup on the coils, so air inside the tank vapor zone should be dehumidified, or special water collection equipment will be necessary.

Avoid spraying parts above the vapor zone or cooling jacket

Spraying above the vapor zone not only generates a vapor-air mixture directly, which is immediately lost, but falling droplets of solvent also disrupt the vapor interface causing more vapor-air mixing.

Reduce exhaust velocities

Vapor control with lip-vent hood exhausts may be too forceful. Use the minimum exhaust velocity that provides proper vapor control in the work area.

Eliminate wind tunnels

Some semi-enclosed machine designs tend to channel and reinforce air current through the machine, especially if power-exhausted. Rearranging the air movement in the room can help to eliminate this wind tunnel effect.

Move the work slowly

Rapid parts or basket movement disrupts the vapor zone and causes mixing with air. Control the hoist speed to less than 11 feet per minute of vertical travel and ensure the proper conveyor speed. Consider installing programmable transporters.

Avoid solvent carry-out

Solvent not allowed to drain properly from parts is lost immediately to evaporation outside the degreaser. Adjust the positioning of baskets or racks to allow easy drainage. Rotate parts if necessary to promote drainage.

Bring parts up to temperature before removal

The cleaning cycle is not complete until the parts have reached vapor temperature and condensation formation has ceased. If condensation is still forming, solvent drag-out will increase.

Dewater the solvent

A water separator can reduce dissolved water in the solvent. Skim water off the surface of the solvent to maintain a reduced water content. Water and solvent form a complex at boiling temperatures which has a lower boiling density than dry solvent vapors and is harder to contain.

Don't overload the degreaser

Avoid inserting oversized items or large baskets into the tank. If the space between the wall of the tank and the work piece is too narrow, than 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.

Repair leaks

Leaks are difficult to detect because of the rapid evaporation of liquid solvent seepage. Careful inspection should be performed routinely, especially in hidden spots.

Consolidate 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.

Locate cold cleaning tanks away from heat sources

Unnecessary and additional heat will substantially increase vapor loss.

4.1.2 Waste Reduction During Aqueous Cleaning and Semi-Aqueous Cleaning

If aqueous or semi-aqueous cleaners are being used to reduce or eliminate the use of hazardous organic solvents, a significant pollution prevention benefit has already been realized. However, a number of pollution prevention practices can still be implemented, including:

- Materials substitution
- Process modifications
- Extending cleaning solution life
- Recycling.

The following sections provide more detailed information on these pollution prevention practices. Recycling is discussed in Section 5.1.2.

4.1.2.1 Use Minimum Cleaner Concentration/Substitute Materials

When selecting an aqueous cleaner (see Table 4-2), use the minimum concentration necessary to obtain the needed level of cleanliness. In addition, avoid aqueous cleaners with hazardous or undesirable components. Similarly, use semi-aqueous cleaners containing the least toxic solvents possible.

4.1.2.2 Modify Processes

Possible modifications for aqueous and semi-aqueous cleaning processes include:

- Explore mechanical surface treatment -- cleaning and stripping of parts can often be accomplished by employing sand, plastic bead, or carbon dioxide pellet blasting techniques.

- Use spray washers or ultrasonic agitation to improve cleaning efficiency
- Use the lowest temperature possible to achieve necessary level of cleanliness.

4.1.2.3 Extend Cleaning Solution Life

Pollution prevention practices to extend cleaning solution life, reduce waste, and reduce raw material purchases include:

- Remove solids and oil frequently or continuously
- Avoid cross-contamination
- Reduce evaporation loss by installing lids on tanks
- Reduce drag-out
- Use appropriate make-up solutions, distilled water.

Many of these source reduction practices are similar to those used to extend the life of solvent cleaning solutions as described previously in Section 4.1.1.3.

Remove Solids and Oil Frequently or Continuously

Removing sludge and skimming off the oil layer frequently or continuously can substantially extend cleaning solution life, reduce waste stream volumes and save on disposal costs, as shown in the following example:

- Waterloo Industries, Inc. of Waterloo, Iowa, installed a separator unit designed to continuously remove sludge and particulate matter from its alkaline bath. Since installation, replacement chemical costs have decreased by 20 percent, the time interval between dumping and total clean-out of the system has increased from 4 to 13 weeks, and maintenance has been reduced--a pump is the only moving part in the cleaning process. This system can also be applied to solvent cleaning operations.

4.1.3 Waste Reduction During Mechanical Surface Cleaning

Abrasive wastes can be reduced by using waste reduction practices such as the following:

- Water-based binders
- Liquid spray compositions
- Control of water level in equipment
- Synthetic abrasives.

4.1.3.1 Water-Based Binders

Water-based or greaseless binders should be used for polishing and buffing. These leave the wheel clean and dry, while oil-based binders often cause it to burn, necessitating an additional cleaning using an alkaline soak. Also greaseless compositions adhere to the wheel surface better to increase wheel life.

4.1.3.2 Liquid Spray Compositions

Most abrasives are applied to the wheel in bar form, with the bar held against the wheel during application. This often leads to the application of an incorrect amount of abrasive. An automatic liquid spray system ensures that the optimum amount of abrasive is always maintained on the wheel. This reduces or eliminates:

- Wheel wear due to compound deficiency
- Compound waste due to over-application
- The requirement for subsequent cleaning (spray compounds are usually water-based).

4.1.3.3 Control of Water Level in the Equipment

Ensuring that enough water is used during the cleaning process decreases the rate of attrition of the abrasive and decreases replacement frequency. Similarly, if not enough water is used, items exiting the equipment will be dirty.

4.1.3.4 Synthetic Abrasives

Abrasive cleaning and deburring of workpieces are 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 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.

4.2 WASTE REDUCTION OPPORTUNITIES DURING METAL COATING

4.2.1 Waste Reduction During Coating Application

Numerous pollution prevention opportunities can be implemented to reduce solvent wastes generated from the application of paint coatings on metal parts. These include:

- Use substitute coating materials
- Convert to "low-waste" curing technologies
- Convert to "low-waste" application technologies
- Improve operator practices
- Implement good operating procedures.

The following sections provide more detailed information on these pollution prevention practices for coating applications.

4.2.1.1 Use Substitute Coating Materials

In some cases, a toxic, high solvent coating material can be replaced with a less toxic one. Reduction or elimination of solvent usage in coatings can be accomplished by employing high solids coatings, water-based coatings, radiation-curable coatings,

powder coatings, or two-component reactive liquid coatings. These coatings are described in more detail in Section 3.2.1.

4.2.1.2 Convert to "Low-Waste" Curing Technologies

In some cases, new curing technologies are required in order to use some of the less toxic coating substitutes discussed previously.

New curing methods include infrared drying, ultraviolet drying, and indirect resistance heating. Waste reduction advantages of such curing technologies include:

- Eliminates the need to blow hot air (with entrained dust), and eliminates or reduces air emissions, air pollution control requirements, and byproduct wastes (emission control sludges) associated with alternative technologies using fossil fuels.
- Facilitates use of less-toxic coating materials and adhesives (e.g., powder coatings, waterborne coatings, UV-curable materials) as substitutes for solvent based coatings (e.g., solvent-based coatings).

4.2.1.3 Convert to "Low-Waste" Application Technologies

Converting to "low-waste" application technologies can substantially reduce waste solvent generated from coating operations. Examples include:

- Use equipment with high transfer efficiency
- Use supercritical carbon dioxide spray delivery system

Use Equipment with Low Overspray

Paint waste can be reduced by using high efficiency transfer equipment that produces lower overspray. The standard method of applying paint is the air spray gun with a typical transfer efficiency of 20 to 40 percent.

Many of the newer spray application systems have shown much promise, with transfer efficiencies greater than 65 percent. These systems, as discussed in Section 3.2.2, include:

- High-volume, low pressure (HVLP)
- Electrostatic
- Dip coating
- Electrocoating
- Flow coating
- Curtain coating
- Roller coating
- Powder coating

Use Supercritical Carbon Dioxide Spray Delivery Systems

Supercritical carbon dioxide can be used in the spray application of coatings to replace the volatile organic solvent fraction that is used to obtain atomization viscosity. This enables applicators to reduce VOC emissions by 30 to 70 percent while continuing

to use higher-molecular-weight polymer systems that give superior coating performance.

4.2.1.4 Improve Operator Technique

The transfer efficiency is also a function of operator skill and training. Implementing better operating practices can reduce paint waste and paint costs.

- Regulate the air pressure on spray guns. Air pressure is often set too high and more overspray is produced.
- Keep the spray gun perpendicular to the surface and at the correct distance from the surface.

4.2.1.5 Implement Good Operating Practices

Several simple operating procedures can help reduce solvent emissions from paint coating operations. Examples include:

- Locate paint drums close to painting operations to reduce needless transport of the drums, and reduce the chance of spillage.
- Use tight fitting lids and spigots to transfer materials. Never pour paint or thinner from large containers to small ones. This will reduce losses due to evaporation and spillage.

4.2.2 Waste Reduction During Equipment Cleanup

Pollution prevention practices to reduce waste generated from cleaning coating application equipment include the following:

- Use substitute cleaning materials
- Implement good operating procedures.

4.2.2.1 Use Substitute Cleaning Materials

The toxicity of equipment cleaning wastes can be reduced by replacing organic solvents with less toxic or nontoxic solutions. Also, replacing solvent usage with high-pressure alkaline solutions reduces the release. See Section 4.1.1.2 for more information on solvent substitutes.

4.2.2.2 Implement Good Operating Practices

The following provides a brief description of good operating procedures to reduce solvent wastes from coating equipment cleaning.

Reduce Cleaning Frequency

By revising production schedules to consolidate production runs or dedicating application equipment to a single type of paint can reduce equipment cleaning waste.

Mix Paints Right Before Application

The quantity of cleaning waste is also reduced by utilizing proportional mixing of paints at the point of paint application; this eliminates the need to clean paint mixing tanks.

Use Proper Cleaning Methods

Suggested improved cleaning methods include:

- Paint cups should be scraped of all dry residual paint before cleaning them with thinner. Cups should never be cleaned by filling them with thinner and stirring them until the paint dissolves.
- Spray guns should be cleaned in an enclosed gun cleaner. Thinner is sprayed into the cleaner where it is condensed for later recovery. This reduces VOC emissions produced by cleaning guns outdoors.

4.0 POLLUTION PREVENTION OPPORTUNITIES

4.1 WASTE REDUCTION OPPORTUNITIES DURING METAL CLEANING

4.1.1 Waste Reduction During Solvent Cleaning

4.1.1.1 Avoid or Reduce the Need to Clean

Re-Examine Important Cleaning Considerations

*Composition of the Part
Contaminant Characteristics
Contaminant Source
Degree of Required Cleanliness*

Convert Upstream Manufacturing Processes to Reduce Subsequent Solvent Cleaning Steps

*Employ "low-waste" metal cutting, forming, and bonding technologies
Substitute materials used in metal cutting, forming, and bonding
Upgrade deburring operations*

4.1.1.2 Use Alternative Cleaning Methods

High-Pressure Hot Water or Steam

Aqueous Cleaners

*Evaluate wastewater quality issues
Determine if organic solvents are a component of your aqueous cleaner
Contact suppliers and test aqueous cleaning alternatives*

Less Toxic Organic Solvents

*Terpenes
Soy-based Solvents
Aliphatic Hydrocarbons
Alcohols
Esters
Amines
Glycol Ethers
Ketones and Aldehydes
Aromatic Hydrocarbons
Halogenated Hydrocarbons
Chlorofluorocarbons (CFCs)
Hydrochlorofluorocarbons (HCFCs)
Hydrofluorocarbons (HFCs) and Fluorocarbons (FCs)*

Mechanical Alternatives

High Quality Cleaning Applications

*Aqueous Cleaning
Semi-aqueous Cleaning
Hydrocarbon Cleaning
Abrasive Cleaning
Non-chelated Cleaning
No Clean Systems*

4.1.1.3 Extend Solution Life

Implement Operating Procedures to Maximize Solution Life

Pre-clean parts before solvent cleaning
Prevent contamination of cleaning solvent
Prevent "drag-in" of water
Use appropriate makeup solution
Promptly remove solids
Use two-stage cleaning
Use ultrasonic or mechanical agitation
Monitor solvent quality and composition

Reduce Drag-out Losses

Lower the concentration of bath constituents
Reduce speed of workpiece withdrawal
Properly position workpiece on the rack
Use air knife
Improve drag-out recovery

Reduce Evaporative Losses

Install lids/silhouettes on tanks
Increase the freeboard space on tanks
Avoid drafts over the degreaser
Control the amount of heat supplied to vapor degreasers
Adjust cooling
Check the water jacket for proper water flow and temperature
Install freeboard chillers in addition to cooling jackets
Avoid spraying parts above the vapor zone or cooling jacket
Reduce exhaust velocities
Eliminate wind tunnels
Move the work slowly
Avoid solvent carry-out
Bring parts up to the temperature before removal
Dewater the solvent
Don't overload the degreaser
Repair tanks
Consolidate cold cleaning operations into a centralized vapor degreasing operation
Locate cold cleaning tanks away from heat sources

4.1.2 Waste Reduction During Aqueous Cleaning and Semi-Aqueous Cleaning

4.1.2.1 Use Minimum Cleaner Concentration/Substitute Materials

4.1.2.2 Modify Processes

4.1.2.3 Extend Cleaning Solution Life

Remove Solids and Oil Frequently or Continuously

4.1.3 Waste Reduction During Mechanical Surface Cleaning

4.1.3.1 Water-Based Binders

4.1.3.2 Liquid Spray Compositions

4.1.3.3 Control of Water Level in the Equipment

4.1.3.4 Synthetic Abrasives

4.2 WASTE REDUCTION OPPORTUNITIES DURING METAL COATING

4.2.1 Waste Reduction During Coating Applications

4.2.1.1 Use Substitute Coating Materials

4.2.1.2 Convert to "Low-Waste" Curing Technologies

4.2.1.3 Convert to "Low-Waste" Application Technologies

Use Equipment with Low Overspray

Use Supercritical Carbon Dioxide Spray Delivery Systems

4.2.1.4 Improve Operator Technique

4.2.1.5 Implement Good Operating Practices

4.2.2 Waste Reduction During Equipment Cleanup

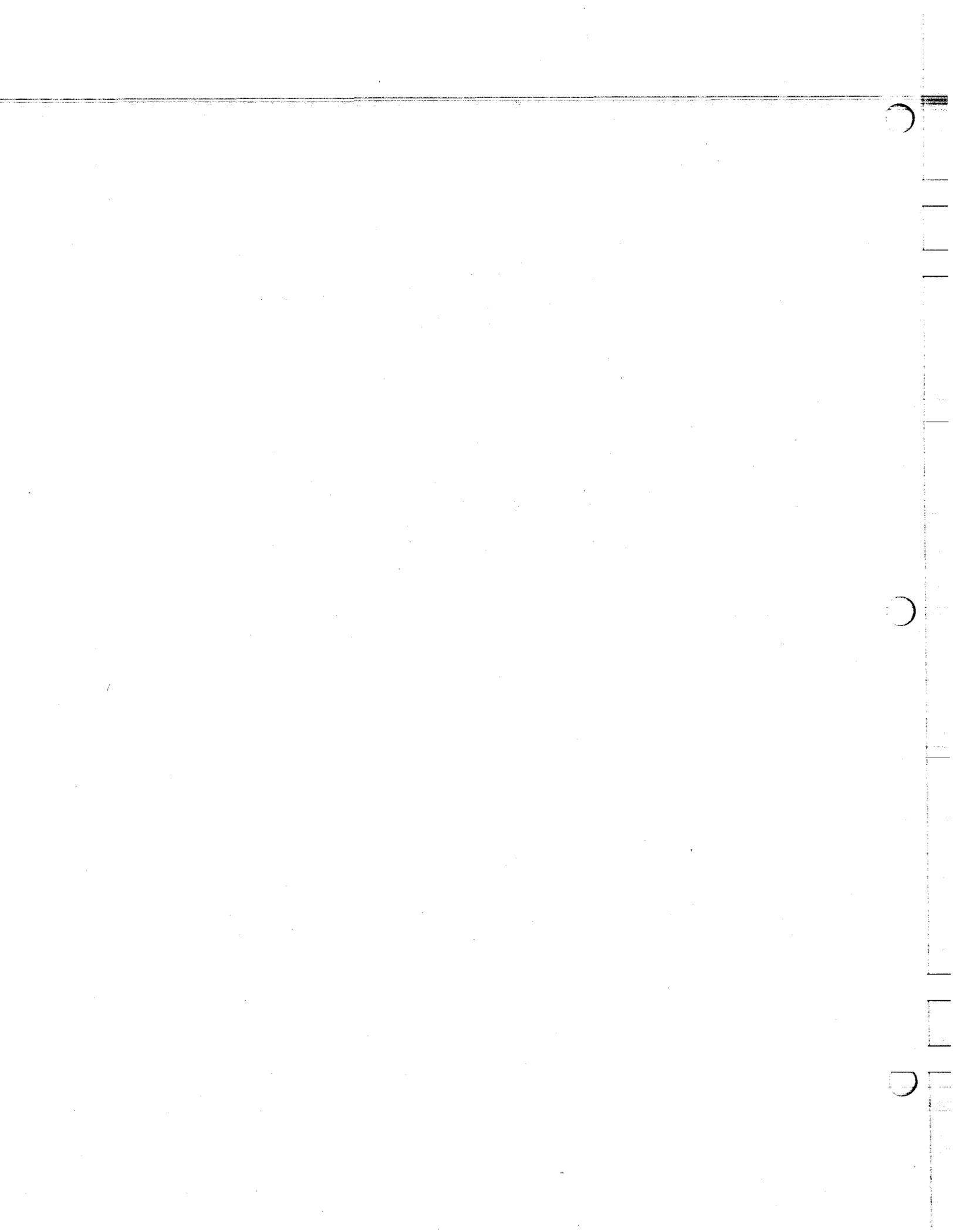
4.2.2.1 Use Substitute Cleaning Materials

4.2.2.2 Implement Good Operating Practices

Reduce Cleaning Frequency

Mix Paints Right Before Application

Use Proper Cleaning Methods



5.0 RECYCLING OPPORTUNITIES

5.1 RECYCLING OPPORTUNITIES DURING METAL CLEANING

5.1.1 Solvent Recycling

Numerous recycling technologies exist, and more are becoming available each day. These are typically characterized in terms of recycling technologies for:

- Spent Solvents
- Solvent Air Emissions

The following sections provide more information on these solvent recycling technologies.

5.1.1.1 Spent Solvents

Common pollution prevention practices to reclaim and reuse spent solvents include:

Downgrade Solvents

In some cases, waste solvent no longer useful for high quality cleaning operations can be reused for a process where the cleaning requirements are less rigorous.

Reduce the Number of Different Solvents Used and Segregate Wastes

Use of the same type of cleaning solvent for as many different operations as possible will facilitate reuse/recycling activities.

Also, be sure to segregate waste solvent from other process wastes. Segregating certain solvents from other non-compatible solvents may also be necessary for recycling.

Remove Solids

In some cases, extensive distillation is not needed to regenerate solvent for reuse. Simple removal of suspended particles is sufficient to reduce fouling. In-line filters may be installed to prevent particulate buildup in the degreaser.

- One electronics controls manufacturer purchased a dozen super-fine filter units to remove particulates from parts cleaning solvents at a cost of \$19,000. As a result, the facility reduced the amount of waste solvent generated from 24 to 4 drums per year, and saved \$96,000 in the first year!
- Waterloo Industries, Inc. of Waterloo, Iowa, installed a separator unit designed to continuously remove sludge and particulate matter from the alkaline bath. Since installation, replacement chemical costs have decreased by 20 percent, the time interval between dumping and total clean-out of the system has increased from 4 to 13 weeks, and

maintenance has been reduced -- a pump is the only moving part in the cleaning process. This system can also be applied to solvent cleaning operations.

Use Emulsion or Dispersion Breaking Chemicals

Emulsion or dispersion breaking chemicals are available to promote the separation of solvent from other solutions, such as oil or water.

Recover Dissolved and Emulsified Organics

Organics separation techniques can be used to concentrate organics for recovery.

Use Industrial Heat Pumps for Solvent Recovery

Industrial heat pumps take heat rejected at some point in the process, raise its temperature, and transfer it to another portion of the process. Industrial heat pumps have recently developed into a commercially viable, energy efficient option for recovery and recycling of waste solvents.

Use Other Distillation, Condensation, and/or Membrane Separation Technologies

Due to recent developments, small solvent recycling units are now commercially available for businesses generating low volumes of waste solvents. The simple heating and condensing systems remove impurities from the solvent waste streams, returning the solvent or the solvent blend to the process which generated it.

In one case, a solvent recovery system was used by a laboratory at Toronto General Hospital. The distillation unit cleaned xylene and chloroform to 100 percent purity and isopropyl alcohol to 99.7 percent. The lab recovered \$180 of solvents per week that would otherwise have required costly off-site disposal.

Numerous manufacturers offer solvent recovery equipment in a variety of sizes. Units with capacities as small as 5 gallons of solvent treated per hour are available. Other units reclaim solvents with a boiling point of 160°C or less in 15-gallon batches, although clean solvent can be drawn off during operation. Recovery levels range from 80 to 99 percent, depending on the amount and type of contamination.

Contract With A Service Company To Maintain Solvent Baths

Solvent service companies will come in on a regular basis to replace old solvent and perform routine maintenance on solvent baths and sinks. In the case of small solvent sink units, some companies allow for the shop to either own or lease the sink. Either way, for such small units the cost for contracted solvent replacement is often less than the costs for purchasing solvent, performing maintenance, and disposing of waste combined.

5.1.1.2 Solvent Air Emissions

In many cases, solvents emissions from cleaning operations can be recovered and reused economically. The systems required for this purpose should be able to recover the solvents in their original, high quality form. A wide variety of processes are applied for this purpose and are shown in Table 5-1.

**TABLE 5-1
SOLVENT AIR EMISSIONS RECOVERY SYSTEMS**

PROCESS	APPLICATION
Low Temperature Condensation	Small volumes of exhaust air; High concentrations
Membrane Technology	Average exhaust air volumes; Average concentrations
Adsorption	All exhaust air volumes; Average concentrations
- Granular Activated Carbon	
- Carbon Fibre	
- Molecular Sieve	
Absorption	Average air volumes; Average concentrations

The most widely used solvent air emission recovery systems include the following:

Activated Carbon Recovery System

In this process solvent-laden air is passed through a bed of activated carbon which acts as the adsorption medium. In the next step the solvent is desorbed or stripped from the carbon. Desorption can be accomplished by several methods including steam regeneration, hot nitrogen regeneration, hot air regeneration, or vacuum regeneration.

Steam is most often used in the desorption/reaction stage of the carbon bed because it is relatively inexpensive, inert, and easily condensed back to the liquid state. In the final step the solvents may be recovered from the mixture through distillation or decantation.

Activated Carbon Fiber Recovery System

The carbon fiber recovery system is an improved version of the granular activated carbon recovery system. Instead of granular carbon, a carbon fiber is used, with all of the adsorbing micropores on the carbon surface. This gives the carbon fiber a higher adsorption capacity than granular carbon and provides high adsorption/desorption rates.

In systems designed for short desorption cycles, the carbon fiber has the following advantages over the conventional granular carbon system:

- Higher quality of recovered solvent
- Less system corrosion problem
- Less risk of carbon bed fires
- Less waste water treatment problems
- More compact and lighter systems.

Liquid Absorption

Removal of solvents from the air stream can sometimes be accomplished using liquid absorption. Typically, an air stream is contacted with a scrubbing solution in which the solvent contaminants are dissolved. The choice of scrubbing solution is central to the success of the process.

Condensation

Condensation of vapors from the gas stream is technically the most straight forward and simple recovery method. If concentrations are high enough, the stream can be cooled using an indirect heat transfer with some refrigerant. For condensation to be economically feasible solvent concentrations must be kept high.

Industrial Heat Pumps for Air Emissions Recovery

Industrial heat pumps have recently been developed into a commercially viable, energy efficient option for recovery and recycling VOC emissions from solvent usage.

Recovery of solvents through condensation may be accomplished by direct cooling of the solvent-laden air stream, or by the use of indirect heat exchangers. Such solvent recovery from exhaust air has been practiced for many years using conventional refrigeration processes, however the thermal energy used for refrigeration was lost to the environment. The use of industrial heat pump technology can conserve this energy while providing an efficient solvent recovery process.

The U.S. Department of Energy (DOE), with cooperation of the Electric Power Research Institute (EPRI) and Southern California Edison (SCC), have jointly sponsored a development program for a process to capture and recycle VOC emissions using a reverse Brayton cycle heat pump. The program demonstrated promising capital cost and efficiency performance at two 3M Company manufacturing plants. Further efforts are underway to develop equipment affordable to the medium and small solvent user.

5.1.2 Aqueous and Semi-Aqueous Cleaning

Aqueous and semi-aqueous cleaning solutions and rinsewaters can be recycled to minimize or eliminate wastewater discharges and to save on waste disposal and cleaner costs.

5.2 RECYCLING OPPORTUNITIES DURING METAL COATING

5.2.1 Solvent Recovery from Air Emissions

Solvents in air emissions from coating processes can also be recovered with techniques described previously in Section 5.1.1.2.

5.2.2 Equipment Cleaning Wastes

Coating application equipment - spray guns, hoses, tanks, etc. is often cleaned with solvents. The resulting solvent cleaning wastes can sometimes be recycled by:

- Separating out the paint sludge through filtration, centrifugation, or decantation, and reusing the solvent.
- Collecting the cleaning wastes and reusing for cleaning - perhaps in another application - until the solvent is too contaminated for further use.
- Some paints require thinning before use. Segregating solvents generated from cleaning according to color will allow you to then use that solvent to thin the next batch of same color paint.

Recycle Solvents On-Site

Purchase of an on-site solvent recovery system may be a viable pollution prevention option for solvent wastes. Due to recent developments, small (5 to 15 gallon) solvent recycling units are now commercially available for businesses generating low volumes of waste solvents. (See Section 5.1.1.1 for more information on solvent recycling.)

Recycle Solvents Off-Site

The sludge produced from drum, spray gun, and paint cup cleaning may contain as much as 50 percent organic thinners. Solvent service companies will visit on a regular basis to replace old solvent generated from parts cleaners. Many of these companies will also accept solvent waste generated from painting operations.

6.0 OBSTACLES TO POLLUTION PREVENTION

6.1 REGULATORY OBSTACLES

Environmental regulations are one of the driving forces behind waste minimization and pollution prevention programs. However, regulatory requirements can sometimes act as barriers to the overall goal of pollution prevention programs. Examples of potential barriers include:

- **Regulatory deadlines** may force industry to focus their limited resources for pollution controls to implement a "quick fix" solution. Lifting the pressures of the deadline could enable the company to re-evaluate their operating procedures in order to create a more comprehensive, long-term compliance plan that incorporates pollution prevention practices. This cost-effective approach to compliance would benefit the facility while reducing pollution emissions.
- **Permitting delays** may also inhibit or delay the use of innovative approaches to pollution prevention. If the pollution prevention practice involves more time, energy, and resources to gain regulatory acceptance than standard end-of-pipe treatment, industry may opt to continue traditional operations. In addition, the reclamation, recycling, or acceptance of another plant's waste as a feedstock may also require compliance with other environmental regulations.
- **Current compliance** with regulations may act as a disincentive to pollution prevention activities. For example, a facility that is already operating in compliance may not realize the long-term benefit of investing more time and resources to develop or expand pollution prevention activities.

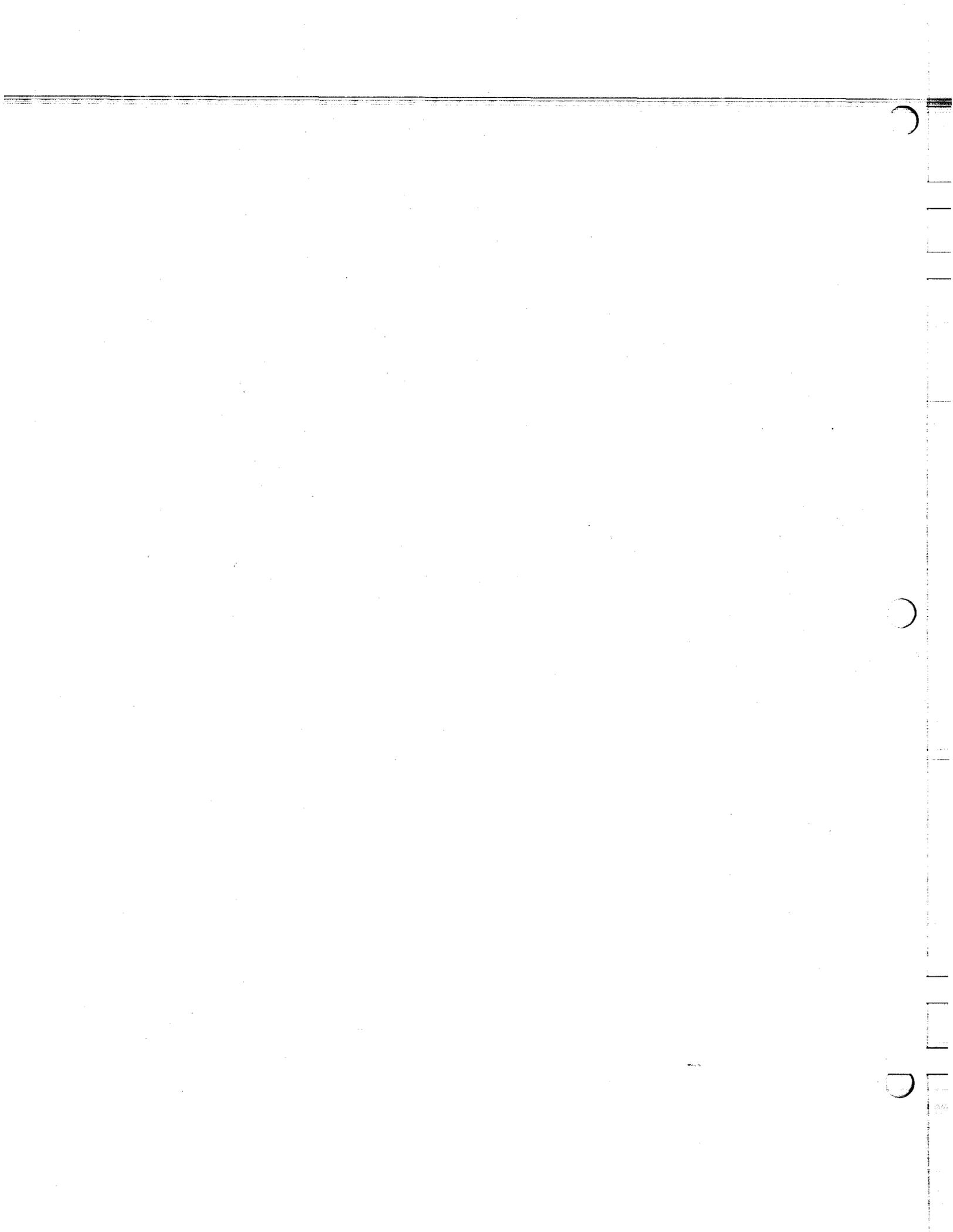
6.2 OTHER OBSTACLES

In addition to regulatory obstacles, other barriers may negatively impact the implementation of pollution prevention programs. Such barriers range anywhere from production to waste treatment procedures and need to be considered when designing a pollution prevention program.

- **Product quality barriers** may inhibit pollution prevention measures if material substitutions (e.g., low solvent or water-based coatings) or process changes result in unsatisfactory cleaning or coating quality.
- **Production barriers** include any changes in the processes in which the product is made. For instance, if a new piece of equipment is used without demonstrating its overall effectiveness, the potential productivity level may not be achieved. Production may have to be delayed or stopped to install the new process equipment. In addition, although the new operating procedure may reduce or eliminate waste, it may also create a bottleneck within the system that could decrease the overall production rate.

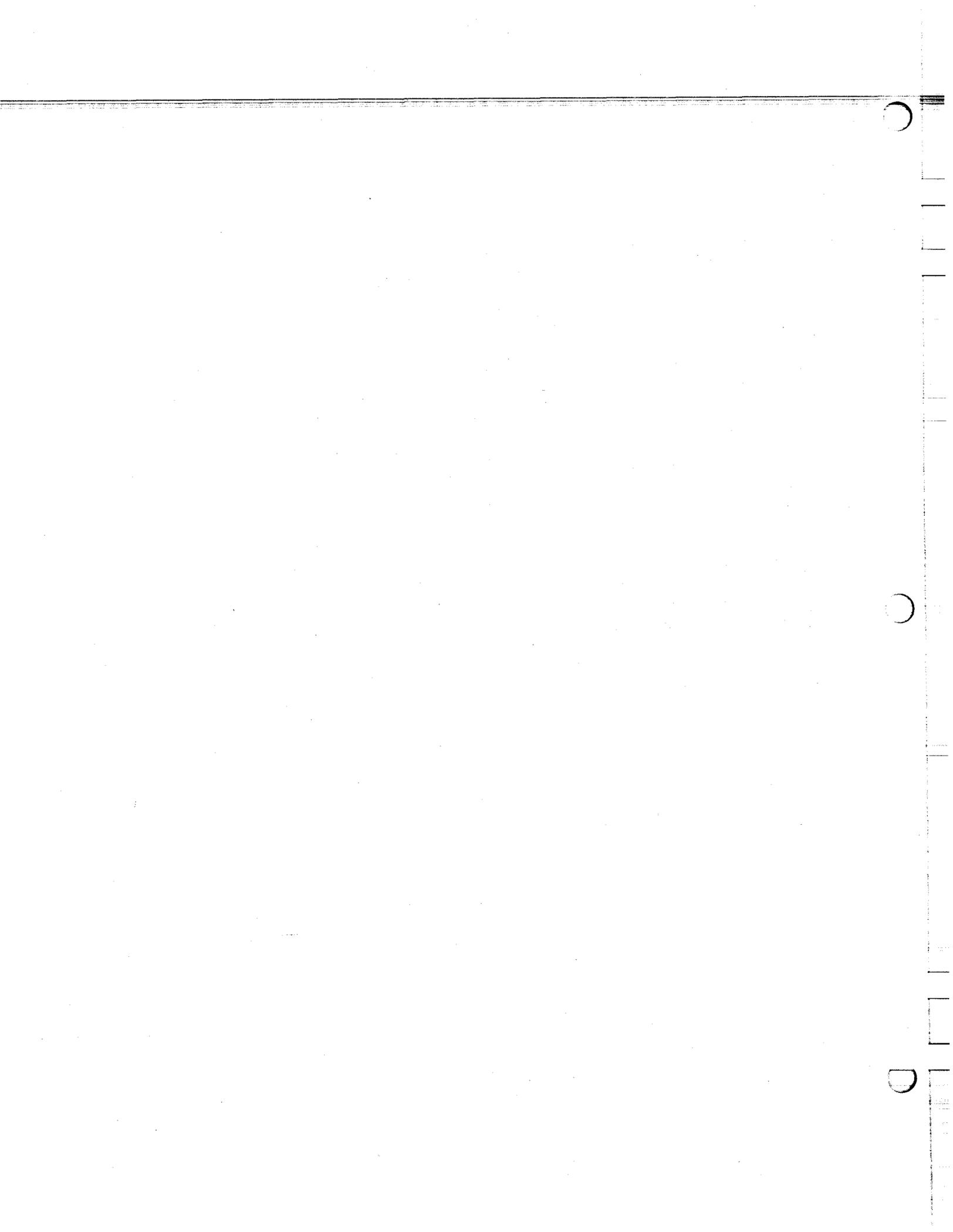
- **Facility barriers** include maintenance and logistical problems that may be difficult to overcome. For instance, some facilities may not have adequate space available or the proper utilities required for the installation of new equipment designed for the pollution prevention program. Construction and engineering assistance may not be readily available to meet a particular project schedule or to provide extensive maintenance that may be required for a specific piece of equipment.
- **Quality control barriers** may result in a work overload to the system that requires constant and immediate attention. More intensive quality control measures on machinery may be needed. In some cases, quality control equipment or procedures may not even be available for new process materials. If substitute materials are used, they may require extensive evaluations to ensure that the production line is still operating properly. New hazards that require special safety procedures may be introduced by the quality control system.
- **Inventory control barriers** impact the practice of reducing inventory levels to avoid having an excess in material output. The reduction of inventory may lead to *stockouts* during high demands on productivity. Also, new types of packaging requirements may call for specific handling equipment for shipment that may not be easily available.
- **Purchasing barriers** occur when existing stocks or binding contracts may delay the replacement of a hazardous material with a non-hazardous substitute. These non-hazardous substitutes may appear to be more expensive up-front until all costs are considered.
- **Investment barriers** include the initial upfront costs for the design and implementation of a pollution prevention program. If the financial resources are not available to purchase new equipment or more expensive materials, the pollution prevention program may never be started.
- **Waste treatment barriers** can be problematic if the use of a new non-hazardous raw material adversely impacts an existing wastewater treatment facility. Process alterations could result in changes in waste stream characteristics and may effect the treatment procedures employed by the disposal facility.

Any pollution prevention program is bound to encounter initial challenges that may hinder the desired level of effectiveness. Therefore, it is essential for facilities to consider several options and alternatives when formulating the basis for a pollution prevention program. Facilities that have had initial waste reduction successes must strive to overcome these barriers to sustain on-going, continuous improvement. Appendix B, which discusses how to develop a "Best-in-Class" Facility-Level Pollution Prevention Program, may provide ways to help overcome these challenges.



APPENDIX A

**CHEMICAL TOXICITY/REGULATORY STATUS CONSIDERATIONS
FOR MATERIALS SUBSTITUTION**



**CHEMICAL TOXICITY/REGULATORY STATUS
CONSIDERATIONS FOR MATERIALS SUBSTITUTION**

TABLE OF CONTENTS

	PAGE
1.1 INORGANICS (INCLUDING METALS)	A-01
1.1.1 Regulated Toxic Metals - RCRA	A-03
1.1.2 Regulated Toxic Metals - Human Health	A-04
1.1.3 Regulated Toxic Metals - Aquatic Organisms	A-05
1.1.4 Other Regulated & Regulated Metals & Inorganics	A-05
2.2 ORGANIC SOLVENTS	A-07

CHEMICAL TOXICITY/REGULATORY STATUS CONSIDERATIONS FOR MATERIALS SUBSTITUTION

Certain chemicals in a waste can cause that waste to be more toxic, or cause the waste to be subject to more stringent waste management requirements -- which in turn can make it more difficult (and costly) to manage, treat, or dispose of the waste. In some cases, materials substitution is an effective means to reduce the toxicity of waste -- and to reduce the regulatory waste management burden.

For purpose of this evaluation, the list of chemicals is divided into the following two general categories:

- Inorganics (including metals)
- Organic Solvents

1.1 INORGANICS (INCLUDING METALS)

Table A-1 provides a comprehensive list of inorganic chemicals, many of which are common ingredients in numerous industrial materials. The chemicals are organized according to the following five categories:

1. Regulated Toxic Metals - RCRA
2. Regulated Toxic Metals - Human Health
3. Regulated Toxic Metals - Aquatic Organisms
4. Other Regulated Metals and Inorganics
5. Unregulated Metals and Inorganics

**TABLE A-1
METALS AND INORGANICS**

	Chemical Name	Regulated Toxic Metals			Other Regulated Metals & Inorganics	Unregulated Metals & Inorganics
		RCRA	Human Health	Aquatic Organisms		
Al	Aluminum				X	
Sb	Antimony		X			
As	Arsenic	X				
Ba	Barium	X				
Be	Beryllium		X			
Bi	Bismuth					X
B	Boron				X	
Br	Bromide				X	
Cd	Cadmium	X				
Ca	Calcium					X
Cl	Chloride				X	
Cr	Chromium	X				
Co	Cobalt			X		
Cu	Copper			X		
F	Fluoride				X	
Fe	Iron				X	
Li	Lithium				X	
Pb	Lead	X				
Mg	Magnesium				X	
Mn	Manganese				X	
Hg	Mercury	X				
Mo	Molybdenum				X	
Ni	Nickel		X			
NO ₃	Nitrate (as N)				X	
NO ₂	Nitrite (as N)				X	
P	Phosphorus, Total				X	
K	Potassium					X
Pr	Praseodymium					X
Se	Selenium	X				
Si	Silicon					X
Ag	Silver	X				
Na	Sodium				X	
Sr	Strontium				X	
SO ₄	Sulfate				X	
Tl	Thallium		X			
Sn	Tin				X	
Ti	Titanium				X	
U	Uranium		X			
V	Vanadium			X		
Zn	Zinc			X		
Zr	Zirconium				X	

1. These compounds are not individually regulated, but will contribute to the "indicator" parameters of TSS and TDS.

1.1.1 Regulated Toxic Metals - RCRA

A waste is classified as a "RCRA Hazardous Waste" if unacceptable levels of any of the toxic metals listed in Table A-2 can leach from it (the maximum acceptable levels, or "RCRA TCLP Limits" are listed under the RCRA column in Table A-2).

TABLE A-2 REGULATED TOXIC METALS -- RCRA											
	Chemical Name	Concentration (mg/l)								Other Guidance	
		RCRA ¹	SDWA ²	WPCA ³				CERCLA ⁴			
		TCLP Limit ⁵	Primary MCL ⁶	Water Quality		POTW ⁷	PP ⁸	313 De-min ⁹	RQ ¹⁰	Level (mg/l)	Ref
				Human Health	Aquatic						
As	Arsenic	5.0	0.050	0.002	0.190	0.830	X	0.1	1		
Ba	Barium	100.0	2.000	1.000	4.100	-	-	1.0	-		
Cd	Cadmium	1.0	0.005	0.010	0.001	0.400	X	0.1	10		
Cr	Chromium	5.0	0.100	0.050	0.050	13.600	X	0.1	5000		
Pb	Lead	5.0	0.015	0.050	0.003	13.200	X	0.1	1		
Hg	Mercury	0.2	0.002	0.001	0.001	0.090	X	1.0	1		
Se	Selenium	1.0	0.050	0.050	0.005	0.047	X	1.0	100		
Ag	Silver	5.0	0.100	0.200	0.001	0.700	X	1.0	1000		

1. RCRA = Resource Conservation and Recovery Act (Hazardous Waste)
 2. SDWA = Safe Drinking Water Act
 3. WPCA = Water Pollution Control Act
 4. CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
 5. TCLP = Toxicity Characteristic Leaching Procedure
 6. MCL = Maximum Contaminant Level established for protection of human health.
 7. POTW = Concentrations industry is allowed to discharge into the municipal sewer system of the Allegheny County Sanitary Authority (Pittsburgh, PA)
 8. PP = Priority (toxic) pollutant regulated by the WPCA
 9. De-minimis emission reporting levels under SARA III, Section 313
 10. RQ = Reportable Quantities for spills of hazardous substances under CERCLA

A waste which the generator believes "may contain any of these substances" must be tested by a laboratory using the Toxicity Characteristic Leaching Procedure, or TCLP test.

NOTE: Any waste generated from a process using raw materials which contain any of these toxic metals is viewed as a waste which "may contain any of these substances" -- and the TCLP test is the only reliable method to determine whether unacceptable levels of these metals can leach from the waste.

If the test, which simulates leaching under landfill conditions, reveals unacceptably high levels of any of these metals, then the waste is considered a **HAZARDOUS WASTE** and is subject to extensive regulatory requirements under the Resource Conservation and Recovery Act (RCRA).

In the event that the TCLP analysis determines that the waste DOES NOT contain any of these metals in excess of the "RCRA" limits (listed under the RCRA column in Table A-2), then generating facility is classified by the environmental regulations as a "Residual Solid Waste Generator" (even though the waste may be liquid in form) and must comply with the residual waste generator requirements.

Note: Even though the analysis may determine that the concentration of RCRA toxic metals in the leachate is less than the "RCRA Limit," these wastes:

- *must still be very carefully managed to avoid potential future liability problems;*
- *will still be relatively difficult and expensive to dispose of.*

1.1.2 Regulated Toxic Metals - Human Health

Table A-3 provides a list of the metals which are regulated by the Safe Drinking Water Act and the Water Pollution Control Act because of their toxicity to human health. Although wastes which contain these metals are not hazardous wastes subject to the extensive RCRA regulatory requirements, they are nevertheless strictly regulated under the Safe Drinking Water and Water Pollution Control acts.

TABLE A-3 REGULATED TOXIC METALS -- HUMAN HEALTH											
Chemical Name	Concentration (mg/l)									Other Guidance	
	SDWA ¹		WPCA ²				CERCLA ³				
	Drinking Water Standards		Water Quality Criteria		POTW ⁶	PP ⁷	313 De-min ⁸	RO ⁹	Level (mg/l)	Ref	
	Primary MCL ⁴	Seco ⁿ y RMCL ⁵	Human Health	Aquatic							
Sb	Antimony	0.006	-	0.010	0.219	0.780	X	1.0	5000		
Be	Beryllium	0.004	-	0.001	-	0.030	X	0.1	10		
Ni	Nickel	0.100	-	0.600	0.029	8.000	X	0.1	100		
Tl	Thallium	0.002	-	0.002	0.013	0.050	X	1.0	1000		
U	Uranium	-	-	0.020	-	-	-	-	-		

1. SDWA = Safe Drinking Water Act
2. WPCA = Water Pollution Control Act
3. CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
4. MCL = Maximum Contaminant Level established for protection of human health.
5. RMCL = Recommended Maximum Contaminant Level established for aesthetics (e.g., taste and odor).
6. POTW = Concentrations industry is allowed to discharge into the municipal sewer system of the Allegheny County Sanitary Authority (Pittsburgh, PA)
7. PP = Priority (toxic) pollutant regulated by the WPCA
8. De-minimis emission reporting levels under SARA III, Section 313
9. RO = Reportable Quantities for spills of hazardous substances under CERCLA

1.1.3 Regulated Toxic Metals - Aquatic Organisms

Table A-4 provides a list of metals which are regulated principally because of their toxic effects on aquatic organisms. These chemicals represent a facility's third priority for materials substitution.

TABLE A-4 REGULATED TOXIC METALS -- AQUATIC ORGANISMS											
	Chemical Name	Concentration (mg/l)								Other Guidance	
		SDWA ¹		WPCA ²			CERCLA ³				
		Drinking Water Standards		Water Quality Criteria		POTW ⁶	PP ⁷	313 De-min ⁸	RQ ⁹	Level (mg/l)	Ref
		Primary MCL ⁴	Secon'y RMCL ⁵	Human Health	Aquatic						
Co	Cobalt	-	-	-	0.019	-	-	-	-		
Cu	Copper	-	1.3	1.0 ¹⁰	0.005	10.400	X	1.0	5000		
V	Vanadium	-	-	-	0.103	-	-	-	-	0.020	11
Zn	Zinc	-	5.0	5.0 ¹⁰	0.060	12.500	X	1.0	1000		

1. SDWA = Safe Drinking Water Act
 2. WPCA = Water Pollution Control Act
 3. CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)
 4. MCL = Maximum Contaminant Level established for protection of human health.
 5. RMCL = Recommended Maximum Contaminant Level established for aesthetics (e.g., taste and odor).
 6. POTW = Concentrations industry is allowed to discharge into the municipal sewer system of the Allegheny County Sanitary Authority (Pittsburgh, PA)
 7. PP = Priority (toxic) pollutant regulated by the WPCA
 8. De-minimis emission reporting levels under SARA III, Section 313
 9. RQ = Reportable Quantities for spills of hazardous substances under CERCLA
 10. water quality criteria established for aesthetics (e.g., taste and odor, staining).
 11. U.S. EPA Office of Water, Drinking Water Regulation and Health Advisories, Nov. 1991

1.1.4 Other Regulated and Unregulated Metals and Inorganics

Table A-5 provides a list of the other metals and inorganics which are regulated by the Safe Drinking Water and the Water Pollution Control Acts. This table also includes those which are not individually regulated, but will nevertheless contribute to the "indicator" parameters of Total Suspended Solids (TSS) and Total Dissolved Solids (TDS). Again, these chemicals are regulated primarily because of their adverse impact on aquatic organisms and, for some chemicals, their impact on drinking water aesthetics (e.g., taste and odor). These chemicals represent a facility's fourth priority for materials substitution.

**TABLE A-5
OTHER METALS AND INORGANICS**

	Chemical Name	Concentration (mg/l)				Other Guidance	
		Drinking Water Standards		Water Quality Criteria		Level (mg/l)	Ref
		Primary MCL ¹	Seco ⁿ 'ry RMCL ²	Human Health	Aquatic		
Regulated							
Al	Aluminum		0.200				
B	Boron						
Br	Bromide						
Cl	Chloride		250.000				
F	Fluoride	4.0	2.000				
Fe	Iron		0.300				
Li	Lithium			0.900			
Mg	Magnesium						
Mn	Manganese		0.050				
Mo	Molybdenum					0.010	4
NO ₃	Nitrate (as N)	10.0					
NO ₂	Nitrite (as N)	1.0					
P	Phosphorus, Total						
Na	Sodium			20.000			
Sr	Strontium					20.000	4
SO ₄	Sulfate		250.000				
Sn	Tin						
Ti	Titanium						
Zr	Zirconium						
Indicators							
TSS	Total Suspended Solids					30.000	5
TDS	Total Dissolved Solids		500.000				
Unregulated³							
Bi	Bismuth						
Ca	Calcium						
K	Potassium						
Pr	Praseodymium						
Si	Silicon						
<ol style="list-style-type: none"> 1. MCL = Maximum Contaminant Level established for protection of human health. 2. RMCL = Recommended Maximum Contaminant Level established for aesthetics (e.g., taste and odor, staining). 3. These compounds are not individually regulated, but will contribute to the "indicator" parameters of TSS and TDS. 4. U.S. EPA Office of Water, Drinking Water Regulation and Health Advisories, Nov. 1991 5. Typical NPDES effluent limit. 							

1.2 SOLVENT TOXICITY

Although organic solvents have excellent cleaning properties, many of them are considered hazardous to human health and the environment. The negative environmental and health-related attributes of solvents, particularly halogenated ones include:

- Toxicity
- Flammability
- Ability to dissolve landfill liners
- Ability to carry other toxics
- High volatility
- Contribution to smog
- Long half-life
- Toxic degradation products
- Resistance to biodegradation
- Stratospheric ozone depletion

In addition, solvent wastes were among the first to be banned from land disposal by the U.S. Environmental Protection Agency.

Table A-6 provides a suggested "toxicity rating" for many common organic solvents used in industrial activities. These solvents are organized into four groups as follows:

Group I

Organic solvents listed in Group I are generally preferred substitutes for those listed in Groups II through IV. These organic solvents are NOT currently:

- Listed hazardous air pollutants (HAP)
- Listed SARA 313 toxic chemicals
- Listed CERCLA hazardous substances
- Suspect or demonstrated carcinogens

Many of these organic solvents are nevertheless flammable or ignitable, and wastes generated from their use may be subject to RCRA regulatory requirements.

In addition, depending on the industrial process and site specific considerations, any organic solvent may emit VOCs which may be subject to the Clean Air Act provisions which require states to attain and maintain National Ambient Air Quality Standards (NAAQS) for ozone.

Group II

Organic solvents listed in Group II are NOT currently listed "hazardous air pollutants" and are generally preferred substitutes for those listed in Groups III and IV. However these organic solvents are:

- listed SARA 313 toxic chemicals and/or
- listed CERCLA hazardous substances

and efforts should be made to identify less toxic substitutes for these organic solvents.

Group III

Group III organic solvents are all listed "hazardous air pollutants," and many are also:

- Listed SARA 313 toxic chemicals
- Listed CERCLA hazardous substances

Group IV

Organic solvents listed in Group IV are all:

- Halogenated (chlorinated) hydrocarbons
- Listed hazardous air pollutants (HAPs)
- Listed SARA 313 toxic chemicals
- Listed CERCLA hazardous substances

Many of these organic solvents are also suspect or demonstrated carcinogens.

**TABLE A-6
COMMON ORGANIC SOLVENTS**

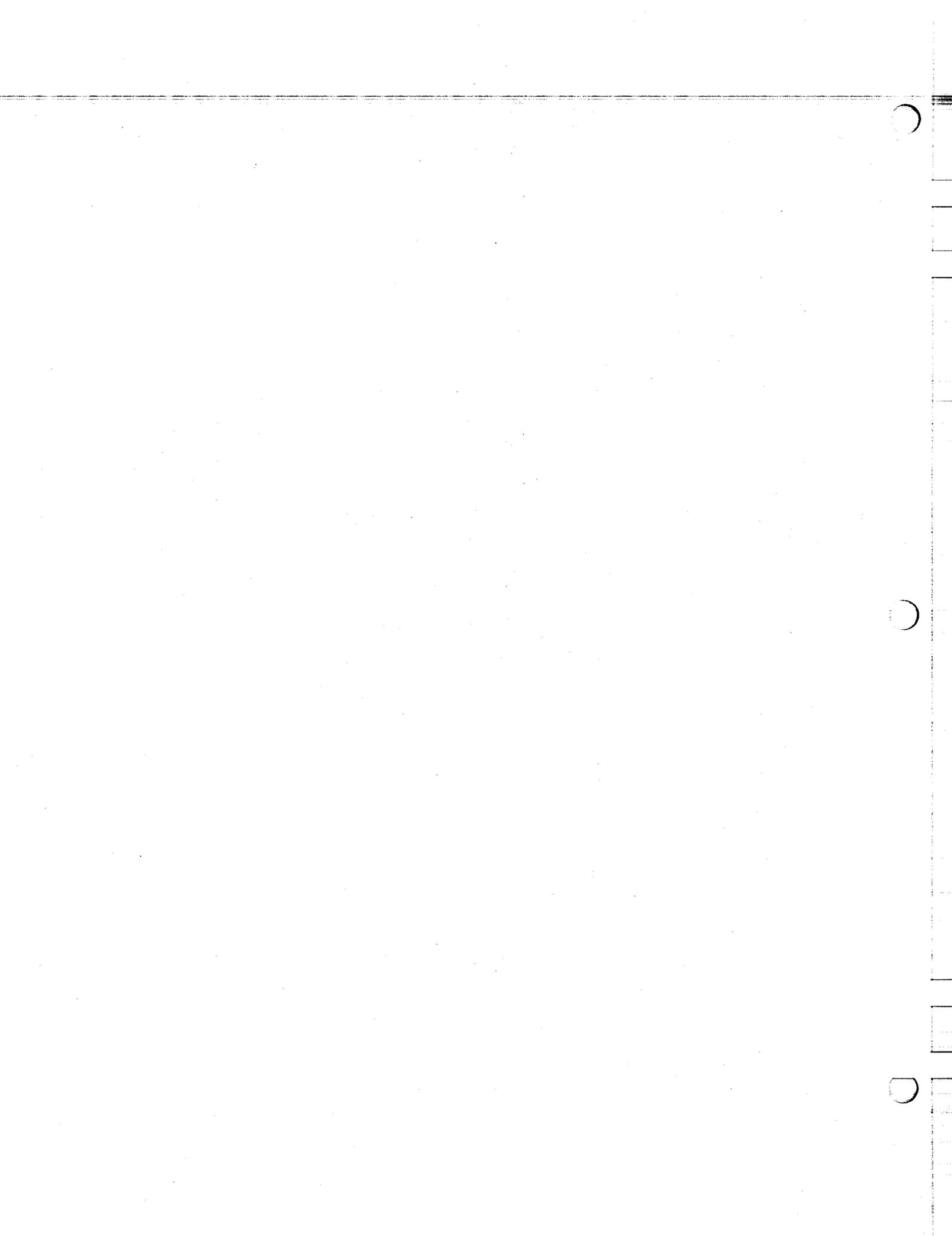
Chemical Name	Category	CAS	TWA	degF F.P.	mm V.P.	CAA HAP	313 Tox.	CERCLA Haz.
GROUP I								
d-limonene (major ingredient of terpenes)	AliHyd	5989-27-5	N.L.	120	-	no	no	no
N-alkyl pyrrolidine (NAP; 2-pyrrolidinone)	Amine	616-45-5	N.L.	230	-	no	no	no
N-methyl-2-pyrrolidine (NMP)	Amine	872-50-4	N.L.	107	-	no	no	no
gamma-butyrolactone (BLO)	Ester	96-48-0	N.L.	210	-	no	no	no
glycol ether acetate	Ester	**	N.L.	**	**	no	no	no
n-butyl butyrate	Ester	109-21-7	N.L.	121	-	no	no	no
isobutyl isobutyrate	Ester	97-85-8	N.L.	99	10	no	no	no
ethyl-3-ethoxypropionate	Ester	763-69-9	N.L.	125	-	no	no	no
ethyl lactate	Ester	97-64-3	N.L.	-	-	no	no	no
propylene glycol mono-methyl ether acetate (glycol ether PM Acetate)	Ester	*	N.L.	114	3.7	no	no	no
ethyl alcohol (ethanol; anhydrous alcohol)	Alcohol	64-17-5	1000	57	44	no	no	no
isopropyl alcohol (isopropanol; rubbing alcohol)	Alcohol	67-63-0	400	50	33	no	no	no
mineral spirits (petroleum distillates/naphtha)	AliHyd	8002-05-9	400	100	40	no	no	no
ethyl acetate	Ester	141-78-6	400	24	74	no	no	no
isopropyl acetate	Ester	108-21-4	250	36	42	no	no	no
butyl acetate	Ester	123-86-4	150	72	15	no	no	no
stoddard solvent	AliHyd	8052-41-3	100	110	40	no	no	no
turpentine	AliHyd	8006-64-2	100	95	5	no	no	no
kerosene	AliHyd	8008-20-6	100	150	5	no	no	no
heptane	AliHyd	142-82-5	85	25	40	no	no	no
GROUP II								
ethyl ether	Ether	60-29-7	400	440	49	no	no	100
acetone	Ketone	67-64-1	250	0	180	no	Yes	5000
sec-butyl alcohol (2-butanol)	Alcohol	78-92-2	100	75	24	no	Yes	no
isobutyl alcohol (isobutanol)	Alcohol	78-83-1	50	82	9	no	no	5000
n-butyl alcohol (n-butanol)	Alcohol	71-36-3	50	99	6	no	Yes	5000
GROUP III								
methyl alcohol (methanol)	Alcohol	67-56-1	200	52	92	Yes	Yes	5000
methyl ethyl ketone	Ketone	78-93-3	200	22	71	Yes	Yes	5000
ethylene glycol monoethyl ether (cellosolve; 2-ethoxyethanol)	GlyEth	110-80-5	200	120	4	Yes	Yes	1000

**TABLE A-6
COMMON ORGANIC SOLVENTS
(Continued)**

Chemical Name	Category	CAS	TWA	degF F.P.	mm V.P.	CAA HAP	313 Tox.	CERCLA Haz.
GROUP III (Continued)								
xylene	AroHyd	1330-20-7	100	78	9	Yes	Yes	1000
toluene (methyl benzene)	AroHyd	108-88-3	100	43	20	Yes	Yes	1000
ethylene glycol	Alcohol	107-21-1	50	230	0.1	Yes	Yes	no
hexane	AliHyd	110-54-3	50	-7	150	Yes	no	no
methyl isobutyl ketone	Ketone	108-10-1	50	73	16	Yes	Yes	5000
ethylene glycol monobutyl ether (butyl cellosolve)	GlyEth	111-76-2	25	143	0.8	Yes	no	no
cyclohexanone	Ketone	108-94-1	25	146	5	Yes	no	5000
morpholine (diethyleneimide)	Amine	110-91-8	20	100	6	Yes	Yes	no
phenol	AroHyd	108-95-2	5	175	0.4	Yes	Yes	1000
pyridine	Amine	110-86-1	5	68	20	Yes	Yes	1000
formaldehyde (formalin)	Aldehy	50-00-0	0.1	140	1	Yes	Yes	100
benzene	AroHyd	71-43-2	0.1	12	75	Yes	Yes	10
GROUP IV								
methylene chloride (dichloromethane)	HalHyd	75-09-02	500	nap	350	Yes	Yes	1000
1,1,1 - trichloroethane (methyl chloroform)	HalHyd	71-55-6	350	nap	100	Yes	Yes	1000
chlorobenzene	HalHyd	108-90-7	75	85	12	Yes	Yes	100
trichloroethylene	HalHyd	79-01-8	25	90	58	Yes	Yes	100
tetrachloroethylene (perchloroethylene)	HalHyd	127-18-4	25	nap	14	Yes	Yes	100
1,1,2 - trichloroethane	HalHyd	79-00-5	10	nap	19	Yes	Yes	100
carbon tetrachloride (tetrachloromethane)	HalHyd	56-23-5	2	nap	91	Yes	Yes	10
chloroform	HalHyd	67-66-3	2	nap	160	Yes	Yes	10
1,1,2,2 - tetrachloroethane	HalHyd	79-34-5	1	nap	9	Yes	Yes	100
Aldehy	Aldehyde							
AliHyd	Aliphatic Hydrocarbon							
AroHyd	Aromatic Hydrocarbon							
GlyEth	Glyco Ether							
HalHyd	Halogenated Hydrocarbon							
*	Propylene glycol mono-methyl ether acetate does not have a CAS #. Its ingredients include 1-methoxy-2-acetopropane (97%) with CAS # 108-65-6; and 2-methoxy-2-acetopropane (3%) with CAS # 70657-70-4. Glycol ether acetate is a generic name for a group of organic solvents.							
**	Not listed by OSHA in Table Z-1-A "Limits For Air Contaminants", 29 CFR 1910.1000							
N.L.	Flash point in degrees F							
F.P.	Vapor pressure mm Hg at 68 degrees F							
VP	Listed "hazardous air pollutant" pursuant to the CAA							
CAA HAP	Listed as a "toxic chemical" under SARA title III, Section 313							
313 Tox.	CERCLA "hazardous substance" reportable quantity							
CERCLA	Not applicable							
nap	Chemical Abstract Service Number							
CAS	Time Weighted Average NIOSH/OSHA recommended exposure limit concentrations ppm for up to a 10-hour workday during a 40-hour workweek							
TWA								

APPENDIX B

**HOW TO DEVELOP A "BEST-IN-CLASS" FACILITY LEVEL
POLLUTION PREVENTION PROGRAM**



HOW TO DEVELOP A "BEST-IN-CLASS" FACILITY-LEVEL POLLUTION PREVENTION PROGRAM

Many facilities have already implemented numerous important and significant source reduction initiatives. In order to build on these successes, and further strengthen a facility's pollution prevention program, it is useful to compare the facility's program to a "benchmark" derived from facility level pollution prevention programs, which are widely regarded as "best-in-class."

In spite of significant initial successes, numerous facilities have discovered that pollution prevention should be an on-going process of continuous improvement. These facilities have found that, over time, even further *cost-effective* reductions can be achieved by integrating and institutionalizing the pollution prevention program within the facility's daily business practice.

In addition, public demands for continuously improving environmental performance is causing federal and state governments to adopt legislation and regulations that are meant to encourage cost-effective source reduction.

However, it is becoming increasingly clear that many of these new requirements are prescriptive in nature and tend to add nonproductive

elements to the pollution prevention process. Regulatory-driven reporting requirements, process requirements, record keeping, and prescribed methods of reduction all have the potential to restrict pollution prevention progress and stifle the creativity and innovation needed for substantial progress.

Many industries view institutionalized continuous pollution prevention improvement as essential for supporting industry's overall pro-active efforts designed to satisfy public demand and reduce the perceived need for any such additional regulatory-driven requirements. By striving for "best-in-class" status, many more industries can provide an important contribution to this effort.

A useful approach is to perform an evaluation of a facility's pollution prevention program compared to the results of the Facility Level Pollution Prevention Benchmarking Study performed by The Business Roundtable (BRT) and published in November 1993.

Of all the facilities that met the BRT's Benchmarking Project Team's selection criteria for a "Best-in-Class" facility level pollution prevention program, the following six were selected for the BRT's benchmarking study:

COMPANY	FACILITY LOCATION	CHEMICAL USER OR MANUFACTURER
Procter & Gamble	Mehoopany, PA	Chemical User
Intel	Aloha, Oregon	Chemical User
Du Pont	La Porte, Texas	Chemical Manufacturer
Monsanto	Pensacola, Florida	Chemical Manufacturer
3M	Columbia, Missouri	Chemical User
Martin Marietta	Waterton, Colorado	Chemical User

The study identified the following 18 critical/essential or important elements found to be common for "best-in-class" facility level pollution prevention programs.

1. Facilities had a clear facility-wide understanding of the definition of pollution prevention -- and had either facility or corporate pollution prevention mission/vision/policy statements.
2. Facilities had a method for identifying and documenting all wastes and emissions.
3. Facilities had pollution prevention goals.
4. Facilities used a facility champion or facilitator or focal point person to lead the program.
5. Facility management was committed to provide necessary resources to support pollution prevention activities. Pollution prevention was a core value at the facility.
6. Facilities integrated pollution prevention into the existing business planning procedure rather than relying on separate pollution prevention plans.
7. Priorities were assigned to waste streams.
8. Cross-functional teams were used. There was an organized effort to motivate employees to suggest and implement pollution prevention initiatives.
9. In order for the facility to sustain its pollution prevention program, most pollution prevention projects had to be cost-effective in order to be implemented. Unlike compliance projects, pollution prevention projects had

to compete in the normal capital process.

10. Pollution prevention progress was tracked and communicated.
11. Facilities used quality tools in their pollution prevention program.
12. Many facilities tied responsibility and accountability for wastes, emissions, and pollution prevention results to the generating operation.
13. The facility did not seek to change its culture, but rather integrated and institutionalized the pollution prevention initiative into its existing culture.
14. Facility recognition programs are used to help sustain employee motivation.
15. Facilities had access to corporate and other outside resources to support implementation of the facility's pollution prevention programs.
16. Effective communication, both within the facility and between facilities, increased pollution prevention awareness.
17. Pollution prevention was integrated into pre-manufacturing (research, development, and design) decisions or choices.
18. Facilities used new technology to achieve significant improvement.

Any assessment of a facility's pollution prevention program should also be heavily influenced by the results of a Quality Environmental Management (QEM) project conducted by the President's Commission on Environmental Quality (PCEQ) under former President Bush. The results of that (QEM) project are summarized in the Commission's January 1993 report

entitled Total Quality Management: A Framework For Pollution Prevention.

The report recommends the following TQM frame-work for pollution prevention, called "Quality Environmental Management" or "QEM."

1. Establish Management Commitment

- involve stakeholders
- define and allocate resources
- empower employees

2. Develop A Quality Action Team

- organize a cross-functional team
- use existing resources and processes
- establish two-way communication with management

3. Awareness and Process Training

- timely
- practical

4. Determine Environmental Impact of Existing Operations

- use QEM tools and methods as appropriate
- identify and fill critical information gaps
- consider how to measure improvements

5. Develop and Select Improvement Projects

- develop project selection criteria
- collect only additional data needed to make decisions
- establish metric baseline

6. Implement Improvement Projects

- inform all site employees of impending improvement project
- empower the QAT to implement the project or obtain the additional resources necessary

7. Measure the Results

- develop metrics
- adjust as necessary

8. Standardize/Institutionalize Improvement and Begin New Cycle

- integrate improvements into other processes and institutionalize such actions as a company "best practice"
- communicate actions to stakeholders
- recognize team and individual performance achievements in ways consistent with company culture
- continue the process

The following provides a summary of a few of the key findings of the President's Commission on Environmental Quality (TQM) report.

- TQM and Pollution Prevention (P2) are complementary concepts -- emission or waste reduction opportunities are most successful when groups of employees with diverse skills and experiences are fully empowered to identify sources of pollution and to make innovative, cost-effective recommendations for addressing identified sources. TQM tools are useful at every step in this process.
- Successful P2 efforts, while dependent on a systematic and rigorous analysis, rely heavily on flexibility in actual application
- There is no universal metric for tracking performance, but there are a number of metrics which can be tailored to a company's needs.
- Consultation and collaboration with stakeholders interested in emission or waste reductions are critical in developing credible progress reports

- Understanding the barriers and incentives to effectively implementing a P2 program is key to increasing corporate commitment & success. Incentives may include:
 - cost savings
 - technological innovation
 - increased public acceptance
 - better relations with regulators

Barriers typically include:

- limited resources
 - inertia
 - uninformed management or employees
 - accounting systems that do not measure environmental costs or values
 - fear of compromising product quality or production efficiency
 - technology limitations
- Even an excellent pollution prevention project must often compete for scarce time (people) and financial resources against several other important projects -- many of which may provide other valuable social benefits such as new jobs, improved process safety, etc.
 - Effective QEM is a continuous improvement process

Indeed, in recent years, literally hundreds if not thousands of pollution prevention success stories have been published, which demonstrate the simultaneous economic and environmental benefits of the pollution prevention approach to improving environmental performance. Numerous pollution prevention guidance documents have also been published to help businesses develop their own pollution prevention programs. Any number of these success stories and guidance documents can be used as a benchmark for assessing a facility's pollution prevention program.

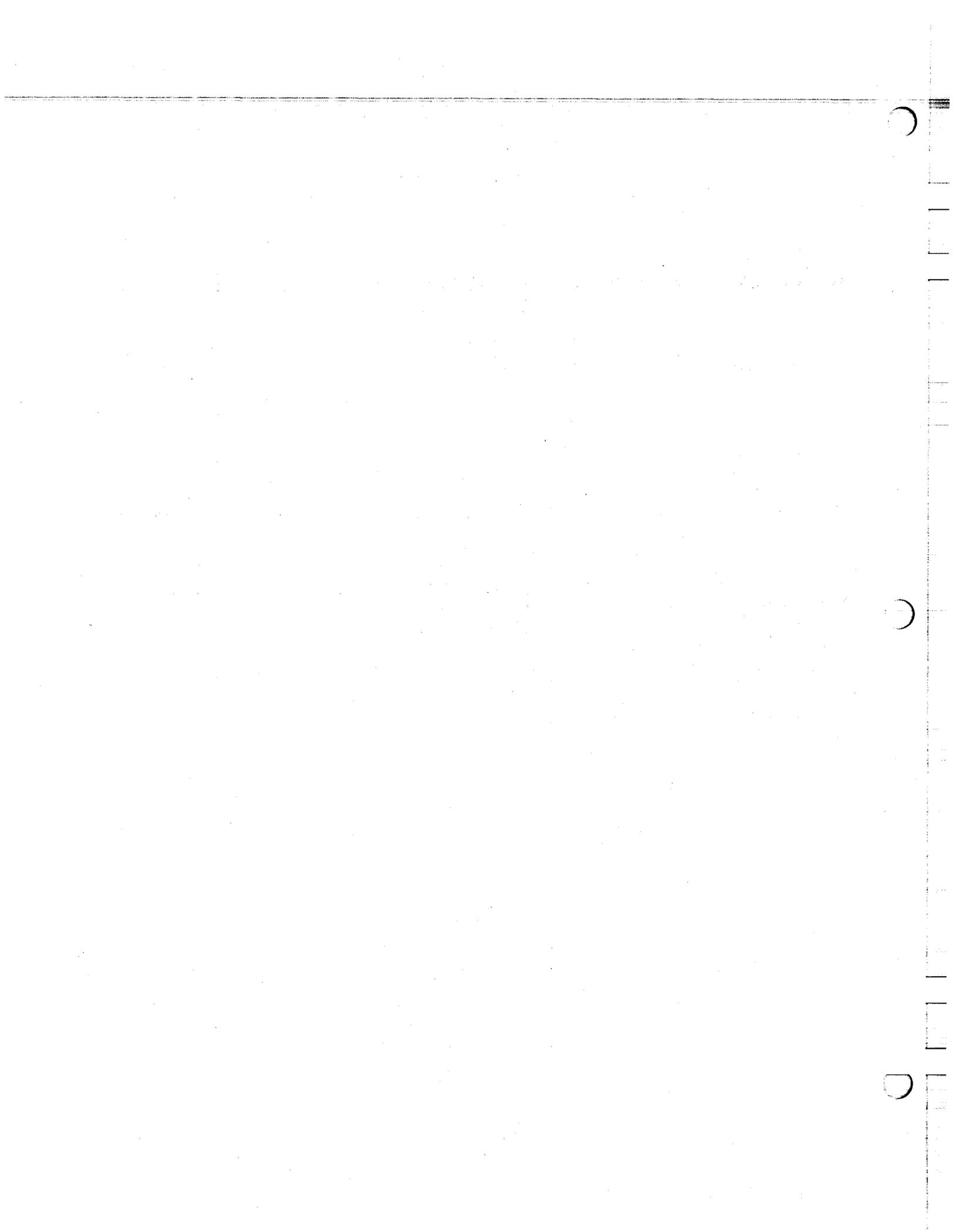
Since 1986, CHMR has provided focused pollution prevention technical assistance and training for business and industry both nationally and internationally. Based on this 9 years of accumulated pollution prevention focused knowledge and experience, it is our position that the two reports discussed previously provide the best and most concise resource to serve as a basis for this assessment.

In summary, facilities should continue to take steps necessary to focus on and provide organizational support needed to promote pollution prevention facility-wide, and thereby achieve "best-in-class" status.

"Industry has historically worked to maximize the efficient use of resources (materials, labor, energy, etc.) needed for the manufacture of its products. Techniques such as recycling, improving operational procedures, modifying processes and even developing new technologies have all been used to reduce the amount of resources needed to produce a product. In recent years, "pollution prevention" and "source reduction" have become key objectives of many industries for improving environmental performance. Many of the same techniques used to maximize resource utilization can be used to reduce the environmental impact that manufacturing facilities can have on the environment."

*Position Paper on Pollution Prevention
The Business Roundtable
March 8, 1994*

APPENDIX C
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